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The Department was presented with an opportunity to test an innovative solution based on the design and construction of a geotextile or geogrid reinforced embankment. Tensar Corporation's TENSAR SR2 soil reinforcing system was selected. Instrumentation consisting of extensometers, slope indicators and survey reference points, was installed during and after construction to monitor the performance of the embankment. Records of horizontal, vertical and slope movement have been collected since completion of construction.

This report evaluates the effect of the TENSAR SR2 on embankment design, constructability, cost and stability; roadway maintenance effort and the effect of time and ultraviolet radiation on TENSAR SR2 integrity.

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DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

TENSAR REINFORCED SOIL

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I. INTRODUCTION

The subject of this report is the design, construction and performance of an experimental, state-designed, soil reinforcement system (SRS) employing a grid-like, high density polyethylene (HDP) material as the soil reinforcing agent in embankments constructed with on-site, native soils as the fill material. SRS are generally less costly than conventional, standard earth retaining systems for structures over twelve feet high and tolerate greater settlement than rigid structures. The Department has been pursuing the application of SRS where cost, aesthetics and constructibility make this type of structure more desirable and competitive than standard earth retaining systems.

A. Problem Description

During the winter flooding of 1982, slope failures occurred at points near Post Miles (PM) 9.85 and 10.05 on Route 84, in San Mateo County. This is just north of the town of La Honda, as shown in Figure 1. The failures were caused by the undercutting of the slope by La Honda Creek, which is a protected spawning habitat for salmon. Restrictions on altering the streambed of La Honda Creek, site geometry, right-of-way limitations and traffic flow requirements at both sites required that the replacement embankments be constructed with oversteepened slopes.

B. Project Overview

Two experimental SRS embankments were constructed to replace the existing slope that failed at two points between the roadway and the river. The embankments were constructed with a stepped-face, oversteepened slope that was greater than 0.75 to 1.00 in places. Construction was completed in December, 1984.

The reinforcing material, generically referred to as "geogrid", is a commercial product, TENSAR SR2, which is manufactured by Tensar Corporation, Inc. TENSAR SR2 is a uniaxial, HDP plastic grid with a tensile strength approaching that of mild steel. This material is resistant to corrosion and ultraviolet radiation and is amenable to design changes during construction.

C. Research Background

The Department has designed and constructed several SRS on past transportation projects. These include Mechanically Stabilized Embankment, tire-anchor timber walls and Hilficker welded wire walls. These structures were instrumented to measure horizontal, vertical and slope movement, stress in the reinforcing elements and pressure distributions within the fill material. The performance of these structures has or will be evaluated.

This was the first opportunity to design and construct an experimental SRS using a plastic fabric; to evaluate construction problems that might arise from the lateral and vertical restrictions of the work area; to make use of a plastic geogrid as the facing material and to evaluate the effects of ultraviolet exposure, soil corrosivity and time on the fabric.

D. Objectives and Scope

The objective, as stated in the research proposal for this research project, was "...to evaluate the physical properties and performance of Tensar geogrids in the field, and to estimate the cost-effectiveness of this product relative to other forms of soil reinforcement." To this end, the structures were instrumented and have been monitored since construction was completed.

The TENSAR SR2 has been evaluated for design, construction and maintenance aspects; for durability of the plastic material with regard to time, ultraviolet radiation and corrosion; for ease of construction associated with installation of the plastic material in sheets; for the resulting stability of the terraces and for cost comparisons with other types of soil reinforcing materials. This report presents the findings of this investigation.

II. TECHNICAL DISCUSSION

A technical discussion of materials testing, design procedures and instrumentation is contained in the paper "LA HONDA SLOPE REPAIR WITH GEOGRID REINFORCEMENT", by Raymond A. Forsyth and Debra A. Bieber, which is included with this report as Appendix A. This paper was presented at the Symposium on Polymer Grid Reinforcement in Civil Engineering which was jointly sponsored by the Science and Engineering Research Council and Netlon Limited (the predecessor of Tensar Inc.) at the Institution of Civil Engineers, Great George Street, London, England in March of 1984.

The design methodology discussed in the Forsyth/Bieber paper provides a rational approach to the design of oversteepened, reinforced embankments. The design was limited by the geometry of the back slope which was configured to top out at the edge of existing pavement. This design, based on estimated strength of the native soil, was developed using the computer program SOILX and was supplemented with hand calculations.

The design was reviewed using the materials testing data from analyses of samples of the embankment material taken during construction and the computer program STABL. The analysis of the original ground or native material indicated it was more competent than the assumed minimum strength of the recompacted embankment. A phi value of 38 degrees and cohesion of 600 pounds per square foot (effective values) were determined and when used in STABL, resulted in a global safety factor of 1.96. The compacted embankment had assumed (minimum) strength values of phi = 32 degrees and cohesion equal to 50 psf resulting in minimum safety factors of 0.78 (unreinforced fill) and 1.20 (Tensar reinforced fill). Fill cross section and failure arcs are illustrated in Figure 2.

A. Design Models

A summary of the available design models that are in use by the Geotechnical Engineering Branch of the Transportation Laboratory is as follows:

1. SOILX

SOILX computes the factor of safety of the unreinforced embankment and provides a printout of the driving and resisting forces associated with the failure circle. These forces can be converted to moments. The resisting moments due to the soil reinforcement layers are computed by multiplying the allowable tensile strength of the geogrid by the moment arm of the layer. The summation of these moments is then added to the resisting moment of the unreinforced layer computed from SOILX to compute a safety factor of the reinforced embankment.

2. STABL

STABL differs from SOILX in that the stability of the reinforced slope can be modeled directly after converting the tensile forces of each reinforced layer into a pseudo value of soil cohesion. This value is computed by modifying the cohesion of the unreinforced soil with a fictitious cohesion. The fictitious cohesion is taken to be equal to one-half the tensile strength of the reinforcement divided by the effective contributory area of soil it is supporting. Addition of the fictitious cohesion to the cohesion of the unreinforced soil is called the pseudo soil cohesion. The effective contributory area is defined as the vertical distance to the midpoint of the layer above and below the reinforcement multiplied by the unit width used in the analysis. The pseudo soil cohesion is distributed over the soil in that layer. Slope stability is calculated as usual.

STABL can be managed to model designs that involve alternating layers of higher and lower strength reinforcing material. The layer of lower strength material need not extend to the full embedment depth of the higher strength material. These design approaches are shown in Tensar Corporation's literature. STABL is also more sophisticated than SOILX in that slope stability calculations can include piezometric surfaces (including confined aquifers) and can be calculated using either total or effective stress soil parameters.

3. STABL4

STABL4 is capable of directly including the effects of tensile forces due to reinforcing elements placed within the embankment. These forces need not be horizontal, but are collinear with the reinforcement layering. This program is typically used for tieback wall design.

B. Geogrid Spacing and Facing

The design of the vertical spacing of the geogrid can be uniformly set at fixed intervals throughout the embankment, as was done in this application. Or, the design of the vertical spacing may be varied or optimized, with increasing distance between layers as the height of the embankment increases, as is shown in some of the TENSAR SR2 design aids. The choice will probably be based on a trade-off between reduced costs of geogrid versus the increased costs of quality control during construction.

Tensar Corporation suggests that slopes of this degree can be constructed without the "wraparound" facing approach. If this could be effected, considerable construction time would be saved and the production rates would increase.

C. Materials Testing

1. Soils

A copy of the log of a boring for soil samples taken from the slide material at PM 9.8 is shown in Appendix B, Soil Sampling & Triaxial Compression Testing. The results of triaxial testing of original ground is also shown in Appendix B. From the triaxial tests, the angle of internal friction, phi, was found to range from 23.5 to 38 degrees. The angle of internal friction of 32 degrees and cohesion of 50 psf used in the Forsyth paper are assumed minimum values based on similar material. Soil gradation for original ground (OG) and fill material (recompacted OG) was:

Size	% Passing	Size	% Passing	Size	%Passing
3.0"	100	#4	66	5M	12
2.5"	99	#8	53	1M	6
2.0"	98	#16	46		
1.5"	95	#30	40		
1.0"	90	#50	34		
0.75"	85	#100	28		
0.50"	76	#200	23		
0.375"	74				

2. TENSAR SR2

The geogrid used was TENSAR SR2, a uniaxial polymer grid with a peak tensile strength of 5,400 lb/ft in the machine direction (MD) dimension, ie, parallel to the direction in which the geogrid is unrolled. The geogrid was tested in the large-scale pull box at the Transportation Laboratory in Sacramento. The geogrid was placed in the box with decomposed granite, phi = 35 degrees, and loaded with an equivalent overburden load of 720 psf. The geogrid was fastened to the pull bar at every other aperture in the grid and pulled in a direction parallel to the MD dimension until failure occurred at a load of 3,000 lb/ft. Subsequent pull testing with the geogrid fastened at every aperture in the grid confirmed the manufacturer's peak tensile strength noted above. Design was therefore limited by the maximum tensile strength of the geogrid. An embedment length of three feet beyond an assumed failure plane was considered sufficient to develop the full tensile strength of the geogrid.

D. Estimated Cost of Materials

The total value of 6,000 square meters of Tensar SR-2 at $4.50 per square meter was $27,000. Two alternatives were evaluated for comparative costs. Tire reinforcement (an alternative Caltrans designed reinforcing system) would have required 4,800 square meters at a cost of $13.45 per square meter for a total estimated cost of $85,000. Bar mat reinforcement would have required 2,060 square meters at a cost of $67.30 per square meter for a total estimated cost of $113,600.

E. Construction

Preconstruction site conditions at both embankments are shown in Photographs #01 and #02. Access to both sites was extremely difficult due to the steep terrain. Working room at both sites was severely restricted between the existing slope and La Honda Creek as shown in Photograph #03.

Construction proceeded generally as outlined below. Typical embankment cross sections, taken from the bid documents, are shown in Figures #4a and #4b.

1. Foundation

Foundation preparation for both embankments consisted of removal of the slide and miscellaneous debris and excavating the original ground to the back slope as shown in Figure #4a. Saturated clay was encountered in the embankment at PM 9.85 at a depth of 30 feet below the roadway. This unsuitable material was excavated and replaced with Class 3 permeable material.

2. Drainage Blanket & Filter Fabric

A one foot thick rock drainage blanket was encased in a filter geogrid and placed against the cut slope. The drainage blanket was increased to two feet in thickness in that area of the slope where the saturated clay was found in the embankment at PM 9.85. Because of the groundwater conditions found at the base of both excavations, the gravel blanket was extended across the base of both excavations, under the unreinforced section, from the toe of the cut slope to the toe of the rock slope. The base of both foundations was graded to slope toward the middle of the embankment where drains (with cleanouts) to La Honda Creek were installed. End drains were eliminated. The drainage blanket was carried to within three feet of the top of both embankments.

3. Unreinforced Section & Rock Slope Protection

The unreinforced section was placed from the foundation to a height of fifteen feet, Photograph #04, and protected from stream erosion by a rock slope. The rock slope, which can be seen in Photographs #08 and #09, was keyed into the original ground to a minimum depth of five feet adjacent to the creek. The Resident Engineer extended the limits of the rock slope protection at both embankments to increase rigidity and stability.

4. Reinforced Section

The reinforced section was placed in two foot-lifts from the top of the unreinforced section to within three feet of the top of the embankment, Figure #4b. Each lift was formed as a step by first placing temporary plywood batter forms as shown in Photograph #05.

TENSAR SR2 was then laid from the face of the cutslope, across the width of the foundation, up the inside face of the plywood and allowed to overhang the plywood to a length of four feet. Straw was placed against the base of the plywood and the lift backfilled, Photographs #06 and #07. Straw was added as backfilling progressed, until the backfilling was completed to the top of the temporary form. The geogrid was then laid back over the embankment, pulled taut with the backhoe or frontend loader and staked to the ground and fastened at the overlap to the adjacent geogrid, Photographs #07 to #09.

5. Construction Problems

No change orders were required for installation of the Tensar geogrid. Installation of the geogrid is labor-and machine-time-intensive requiring extensive manual manipulation of the geogrid to cut, place, overlap and fasten to the adjacent sheet prior to burial. The ends of each step were squared off and tucked into the original ground as shown in Photographs #10 and #11.

6. Extensometer Installation

Extensometers were installed during construction of the embankment at PM 9.85 at two levels. Two sets were installed each on the second and thirteenth steps.

The extensometers measure horizontal or outward movement of the embankment. They are constructed by fastening rods to the geogrid, Photographs #12 and #13, at various distances from the face of the embankment. The rods pass through PVC pipe, Photograph #14, and extend out the face of the embankment. The PVC pipe isolates the rods from the effects of potential skin friction that could be imposed on the rods by the moving soil mass. The anchor rod is laid alongside the extensometer rods. This rod is firmly fastened, Photograph #15, in the original ground behind the drainage blanket and passes through PVC pipe to the face of the terrace. The ends of the rods are cut off evenly, Photograph #16, and thereafter, any outward movement within the embankment is reflected as a progressive increase in the distance, Photograph #17, between the ends of the rods fastened to the geogrid and the end of the anchor rod fastened in the original ground.

7. Actual Cost

The actual cost of constructing the embankments, including change orders, was $127,000.

F. Postconstruction Instrumentation

Slope indicators were installed and reference points were established after construction was completed.

1. Slope Indicators

Slope indicators were installed at the approximate centerline of each embankment just outside of the asphalt drain on the shoulder, see Figure #5. Indicator #SR1 was installed in the embankment at PM 9.85 to a depth of 46 feet. Indicator #SR2 was installed in the embankment at PM 10.05 to a depth of 28 feet. The casing heads rise 3 to 6 inches above the ground and have a locking cap to protect the casing from vandalism, Photograph #18 (arrow). Logs of the borings are shown in Appendix C. Both logs show that the embankment is about 13 feet thick at the slope indicators.

2. Reference Points

Reference points were established at both embankments, see Tables #4 and #5, to measure settlement. The reference points, which are used to record elevation changes only, were referenced to an assumed datum of 1000 feet.

G. Postconstruction Monitoring

The performance of the embankments has been monitored using the instrumentation and reference points described above. Movement of the embankments, summarized in Table #1, is within acceptable limits. The monitoring data are discussed and evaluated below.

1. Fill at PM 9.85

a. Horizontal Movement

The extensometer data record is shown in Table #3. Six measurements were made through August 28, 1985, when it appeared that the rate of movement was leveling off. No additional measurements were made until the last one was taken on April 16, 1987. The maximum horizontal movement recorded is 0.19 foot. This movement was recorded in the upper, west set of extensometers. This movement has occurred over 28 months and constitutes a rate of movement of 0.08 foot per year.

Fifty-four percent of the average horizontal movement of all four sets of extensometers had already occurred by the end of construction when the first extensometer measurement was made on December 19, 1984. Further, eighty two percent of the average horizontal movement had occurred within eight months of completion of construction, when measurements were made on August 21, 1985.

An additional feature of the extensometer movement was that all rods fastened to the geogrid were moving the same amount regardless of the distance from the face of the embankment at which the rod was fastened to the geogrid.

b. Vertical Movement

Reference point data are shown in Table #4. The elevations of the reference points were recorded in April, May and August of 1985 and on April 16, 1987. The maximum vertical movement, 0.77 foot, was recorded on top of the anchor rod PVC casing in the upper, east set of extensometers. This movement has occurred over 24 months and constitutes a rate of movement of 0.38 foot per year.

In contrast to the horizontal movement, most of which occurred during and immediately after construction, ninety percent of the total vertical movement occurred in the postconstruction period after the August, 1985 measurement.

A number of reference points were lost for various reasons one of which was resurfacing. Route 84 was scheduled for resurfacing during the summer of 1986. This work was carried out as scheduled. There were no surface cracks at the time of resurfacing to indicate movement of the embankments. Resurfacing covered several reference points.

c. Slope Movement

Slope indicator measurements were made on a monthly or bimonthly basis for the first year after construction. Three measurements were made in 1986, three in 1987 and the last one was made in May, 1988.

The maximum slope movement, recorded over a period of 40 months, is 0.74 inch. This constitutes a rate of movement of 0.22 inch per year. The thickness of the embankment material at Slope Indicator #1 is about 13 feet. Movement of the original ground is negligible.

2. Fill at PM 10.05

a. Vertical Movement

Reference point data are shown in Table #5. Elevations of the reference points were recorded in April, May and

August of 1985 and in April 1987. The maximum vertical movement recorded was 0.73 foot. This movement was recorded on a turning point about midway down the face of the embankment. This movement occurred over 24 months and constitutes a rate of movement of 0.36 foot per year.

Eighty eight percent of the total movement occurred between the August 1985 and the April 1987 measurements.

b. Slope Movement

Slope indicator measurements for SI-2 were made on the same schedule as for SI-1. The maximum slope movement, recorded over a period of 40 months, is 2.89 inch. This constitutes a rate of movement of 0.87 inch per year which, while not of immediate concern, is sufficient to suggest continued monitoring. The thickness of the embankment material at Slope Indicator #2 is about 13 feet. Movement in the original ground is insignificant.

3. Slope Movement Summary

These data are best presented as movement versus depth and movement versus time as shown in Figures 3a and 3b. The most notable features of these two figures is that movement has stabilized with time and that movement is limited to the embankment. The underlying native soil is not moving significantly.

The slope indicator instrument used is a DIGITILT model 25689 manufactured by Slope Indicator Company. The instrument is precise, however, measurements may be inaccurate due to a number of causes. Since the casing heads are close to the edge of the pavement, it is logical to suspect that they both have been subject to disturbance. Evidence of a vehicle going off the road, down the embankment and then being pulled back up over the edge of the embankment was found at PM 9.85.

III. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

The reinforced embankments have exhibited reasonable stability since initial postconstruction settling. The TENSAR SR2 has proven to be an acceptable, cost-effective reinforcing material. Specific conclusions are as follows:

1. Construction

Installation of the geogrid was both labor- and machine-time-intensive. It was necessary to place the geogrid by hand and to hold it taut with the backhoe until it could be secured by hand. As stated in the construction notes, "The mesh reinforcement itself required a large amount of handling during the cutting, placing and overlapping process. All of these factors contributed to slow progress in construction."

The geogrid must be stretched tight around the face of the terrace and held by backhoe or frontend loader teeth until fastened to the ground and clipped to the adjacent grid.

Hand placement of straw at the face of the terrace, between the geogrid and soil, as backfilling progresses, also slows the progress of installation. The ends of each terrace must be squared off and tucked into original ground. This requires additional time and labor to cut and form the geogrid into the required shape and to backfill those areas by hand.

All of these factors combined to result in a production rate of only 171 square yards per day as shown in the Construction Completion Report (Appendix D).

2. Performance Evaluation

The observed movement of the embankments is considered acceptable. Movement of the embankment material, as recorded by the slope indicators in both embankments, follows a cyclic pattern in which the winter and spring movement is more rapid than the summer and fall movement. Movement during the second year of monitoring was less than the first year. Movement during the third year was less than movement during the second year.

No movement of the original ground has been detected in the slope indicators. Movements are summarized in Table #1 and discussed in Section IV., F.

Immediately after construction the pavement cracked at both embankments as shown in Photographs #19 and #20. The cracking was controlled by minor patching and did not reoccur prior to scheduled resurfacing in 1986.

Both embankments are westward facing slopes bordered by tall trees which mitigate the effects of ultraviolet radiation to some degree. The exposed geogrid shows no visible evidence of deterioration. It is flexible under foot and, when deformed, returns to its original shape upon release. In October 1987, samples of the geogrid were tested to failure. The test results are listed in Table 2. Buried geogrid had approximately the same strength as geogrid that had been held in storage. The strength of exposed geogrid has decreased up to 10.6 percent.

The straw has decayed, leaving voids behind and under the geogrid and the surface of the embankment is slowly changing from "step-like" to a more or less continuous slope, Photographs #21 thru #23. Moving about on the steps of the slope is becoming increasingly difficult and staff should be cautious when doing so.

Minor evidence of soil erosion was observed. Eroded material is probably washed out of sight into the next lower level and eventually into the riprap at the bottom of the slope.

B. RECOMMENDATIONS

Although there are some minor problems with using the TENSAR SR2 backed with straw for the facing of the terraces, the use of TENSAR SR2 is recommended for those projects where it is determined to be the most cost-effective application of MSE technology.

The design of reinforced embankments, whether for repair, widening or new projects, will require both skill and judgment on the part of the design engineer in the selection and application of the most appropriate design methodology. Each project will be subject to unique site-specific conditions that the design engineer must accommodate in order to produce a safe and economically designed project.

Likewise, the construction of these embankments will require similar exercise of skill and judgment by the resident engineer in accomplishing the successful implementation of the project. These recommendations will assist both the design engineer and the resident engineer in their respective efforts to accomplish these goals.

1. Design

The computer models available to the design engineer are SOILX, STABL and STABL4. The choice by the design engineer of SOILX, STABL or STABL4 will depend on personal knowledge and/or preference. Since the design results will be equally satisfactory, regardless of which method is used, the Transportation Laboratory does not recommend one model over another. However, it is noted that STABL4 does have the most versatility.

All three models require similar input, but differ in the treatment of reinforcing elements and other elements of output. The models are briefly discussed in the section on Design Methodology.

The Transportation Laboratory recommends that design engineers apprise themselves of the design aids provided by the manufacturers, including Tensar Corporation, for reinforcing slopes. The design engineers should be aware that these design aids may have to be modified or may be inappropriate to meet specific field conditions, especially for slope repair projects.

In the circumstances of this project, it was reassuring at the time of report preparation that the original design, which was based on soil test data of the in situ slide material, could be confirmed by an independent design review, based on soil test data of the embankment material and a different computer model.

2. Construction

a. Soil Retention

The design called for 3 inches of straw to be placed between the soil backfill and the inside of the grid on the face and top of each terrace. The straw was used to retain the soil within the geogrid as backfilling occured; to prevent the soil from falling through the geogrid while the terrace was formed; to prevent the soil from washing out of the terrace face; and to provide a source of organic matter for the subsequent rooting of vegetation.

It appears that more than 3 inches of straw was used in some places. The straw has now decayed, allowing voids to form under the geogrid. This leaves the geogrid unsupported and in some places the geogrid has deformed to approach a more natural slope. In other places, the geogrid is unsupported by any underlying materials. Both of these conditions make walking on the embankment difficult. Straw used in future projects should be kept to ~3 inches.

TENSAR SR2 is quite slick and one must be careful not to slip and fall while walking on the terraces. The soil could be retained by placing a finer mesh geogrid between the TENSAR SR2 and the soil. This geogrid should be resistant to the effects of ultraviolet radiation and should be of a sufficiently fine mesh to hold the soil in place yet still permit grass to root.

b. Vegetative Cover

A cover of annual grasses to reduce ultraviolet effects must be established. Cover may be initiated by hydroseeding to facilitate the growth of grass on the slope. The growth of large perennial vegetation should be controlled.

c. Squaring and Tucking Ends of Steps

The ends of the steps must be squared off and tucked into original ground. It appears, Photographs #10 and #11, that much more than 3 inches of straw underlies the geogrid. It may be preferable to have the Contractor make the steps convergent with the natural slope rather than forming a prominent corner composed predominantly of straw.

d. "Overlap" Facing

Slopes which can be constructed with an overlapping, rather than a wraparound, facing should be considered.

3. Performance Monitoring

a. Extensometers

All extensometers moved the same amount at once, thus fewer rods might be used in future studies. Since most of the horizontal movement occurred by the time construction was complete, measurements in future studies should begin as soon as the next lift is in place.

b. Reference Points

Reference points should be installed such that recovery is maximized and could be installed during construction. Points could be anchored on the top of one layer and then extend through subsequent layers to the surface of the slope.

c. Slope Indicator SI-2

Annual slope indicator measurements should be continued until movement drops to a level similar to that in SI-1.

d. Future Testing of TENSAR SR2 from the Embankments

Samples of TENSAR SR2 from the embankments should be tested, as discussed in Table #2, every 3 to 5 years.

IV. IMPLEMENTATION

Based on the results of this research, performance on other sites constructed by the Department and an evaluation of published reports and manufacturer's test data, the Tensar product is accepted conditionally for use as slope reinforcement without a facing and for use in a stepped-face embankment with the facing constructed of Tensar. To implement the findings of this research project, Caltrans highway Design Manual Section 210.1(2), "State Designed Earth Retaining Systems Which Require Special Designs" will be amended to include provisions for all districts to use geogrid reinforced embankments with design by Translab.

In the interim, a memorandum, will be prepared for distribution to the District Material Engineers stating the amended clause, providing draft specifications and describing situations where use of geogrids should be considered.

The draft specifications will apply to Tensar as well as other geogrids fabricated of different materials. While not specifically part of this research effort, other geogrid products which employ different materials are believed to perform similarly enough in the applications described to allow their use. Selection of the geogrid product to use will then be based upon an economic evaluation by the Contractor.

Review of published reports and technical journals and an ongoing informal monitoring of all Department Tensar projects will continue and will form the basis for any change to the conditional acceptance of the Tensar product and other geogrid products.

VI. CONCURRENT RESEARCH LITERATURE AND REFERENCES

01. Bressette, T. & G. H. Chang, "Mechanically Stabilized Embankment Constructed with Low Quality Backfill", California Department of Transportation, Report Number FHWA/CA/TL-86/06, June 1986.

02. Science and Engineering Research Council & Netlon Ltd., Institution of Civil Engineers, "Symposium on Polymer Grid Reinforcement in Civil Engineering", March 1984.

03. Forsyth, R. A. & D. A. Bieber, "La Honda Slope Repair with Geogrid Reinforcement", Paper 2.2, "Symposium on Polymer Grid Reinforcement in Civil Engineering", March 1984.

04. Chang, J. C., J. B. Hannon, and R. A. Forsyth, "Field zperformance of Earthwork Reinforcement", Report Number FHWA/CA/TL-81/06, 1981.

05. Hannon, J. B., "Long Term Performance of the First Reinforced Earth Wall in California", California Department of Transportation, Final Report Number FHWA/CA/TL-80/27, August 1980.

06. Mundy, P., "Evaluation of Tensar ER-2, a Netlon Product, for use in Mechanically Stabilized Embankments", Rough Draft of Report #19107-641139 of 7/11/80.

07. Chang, J. C., "Long Term Field Behavior of a Reinforced Earth Wall", California Department of Transportation, Interim Research Report Number FHWA/CA/TL-2166-78/05, February 1978.

08. Chang, J. C. and R. A. Forsyth, "Performance of a Reinforced Earth Fill", Transportation Research Report Number 510, Soil Mechanics, Transportation Research Board, National Academy of Sciences, Washington, D. C., 1974.

09. Chang, J. C., "Earthwork Reinforcement Techniques", Final Research Report Number CA-HY-TL-2115-9-74-1, Transportation Laboratory, California Department of Transportation, Sacramento, California, September 1974.

10. Vidal, H., "The Principal of Reinforced Earth", Highway Research Record Number 202, Pages 1-16, Washington, D. C., 1969.

Table #1. SUMMARY OF MOVEMENTS IN THE FILLS

FILL	HORIZONTAL MOVEMENT (Extensometers)	VERTICAL MOVEMENT (Ref. Pts.)	SLOPE MOVEMENT (Slope Ind.)
PM 9.85 (SI-1):			
Maximum Recorded:	0.19 foot	0.77 foot	0.74 inch
Period of Record:	28 months	24 months	40 months
Rate of Movement:	0.08 foot/yr.	0.38 foot/yr.	0.22 inch/yr.
PM 10.05 (SI-2):			
Maximum Recorded:	__	0.73 foot	2.89 inch
Period of Record:	__	24 months	40 months
Rate of Movement:	__	0.36 foot/yr.	0.87 inch/yr.

TABLE 2. SINGLE RIB TESTING OF TENSAR SR2 GEOGRID

SAMPLE DESCRIPTION	POUNDS OF BREAKING FORCE	
Translab stored geogrid, same as in La Honda embankments.	Test #1 = 378 Test #2 = 383 Average = 380	Test #1 = 395 Test #2 = 396 Test #3 = 393 Average = 395

It is assumed that the difference between the breaking strengths in these tests is due to the gripping method and that the results of the 12/87 test are the most reliable. Therefore, the 10/87 test data may be increased by a factor to bring the results closer to the 12/87 data. It seems logical to use a factor based on the averages of the tests, 395/380 = 1.039.

		ADJUSTED TO 12/87 TEST
Upper fill, sun:	Test #1 = 364 Test #2 = 366 Test #3 = 307 Test #4 = 322 Average = 340	Test #1 = 378 Test #2 = 380 Test #3 = 319 Test #4 = 335 Average = 353 Change = -42 or -10.6 %.
Upper fill, shade:	Test #1 = 360 Test #2 = 382 Test #3 = 386 Average = 376	Test #1 = 374 Test #2 = 397 Test #3 = 401 Average = 391 Change = -4 or -1.0% %.
Lower fill, sun:	Test #1 = 325 Test #2 = 393 Test #3 = 353 Average = 357	Test #1 = 338 Test #2 = 409 Test #3 = 367 Average = 371 Change = -24 or -6.1 %.
Lower fill, buried:	Test #1 = 384 Test #2 = 383 Test #3 = 386 Average = 384	Test #1 = 399 Test #2 = 398 Test #3 = 401 Average = 399 Change = + 4 or +1.0 %.

Tensar Corporation supplied Translab with recently manufactured SR2 which was tested as shown below. The test values agree with the breaking strength claimed by Tensar Corporation for the product. These values are about 45 pounds, ~10 percent, higher than the SR2 used in the embankments.

Supplied by Tensar Corp., November, 1987	Test #1 = 439 Test #2 = 439 Test #3 = 440

Table #3. EXTENSOMETER DATA FOR THE FILL AT PM 9.85 IN FEET

DATE	UPPER LEVEL MOVEMENT				LOWER LEVEL MOVEMENT				
	West Set	East Set	Set Avg.	% of Set	West Set	East Set	Set Avg.	% of Set	% of Total
Install	0.000	0.000	0.000	---	0.000	0.000	0.000	---	
12/19/84	0.130	0.110	0.120	67	0.020	0.100	0.060	42	54%
01/23/85	0.140	0.130	0.135	75	0.050	0.130	0.090	62	
03/12/85	0.150	0.140	0.145	81	0.050	0.150	0.100	69	
04/10/85	0.150	0.140	0.145	81	0.070	0.150	0.110	76	
08/21/85	0.150	0.145	0.148	82	0.070	0.150	0.110	76	
08/28/85	0.157	0.146	0.152	84	0.078	0.156	0.117	81	82%
04/10/87	0.190	0.170	0.180	100	0.110	0.178	0.144	100	

Maximum	0.190

Table #4. ELEVATION OF REFERENCE POINTS FOR THE FILL AT PM 9.85

Reference Points	Reference Point Elevations Measured in Feet 4/85	5/85	8/85	4/87	Elev. Change
SN-1	1004.61	1004.59	1004.57	lost	-0.04
SN-2	1003.23	1003.26	1003.27	lost	+0.04
SN-3	1002.40	1002.39	1002.40	lost	0.00
SN-4	1002.31	1002.29	1002.29	lost	-0.02
SN-5	1002.08	1002.05	1002.05	lost	-0.03
Top Fill	1003.10	1003.08	1003.09	1002.36	-0.74
Anchor-1	993.98	993.95	993.89	993.21	-0.77 Max.
Anchor-2	993.17	993.14	993.04	992.45	-0.72
Tur. Pt.	983.67	983.65	983.65	lost	-0.02
Anchor-3	971.84	971.83	971.43	971.10	-0.74
Anchor-4	971.94	971.92	971.93	971.20	-0.74
Rk.Pt.-1	968.28	968.28	968.29	967.61	-0.67
Rk.Pt.-2	961.55	961.55	961.57	960.87	-0.68
Rk.Pt.-3	957.98	957.99	958.00	lost	+0.02

Reference Point Footnotes:

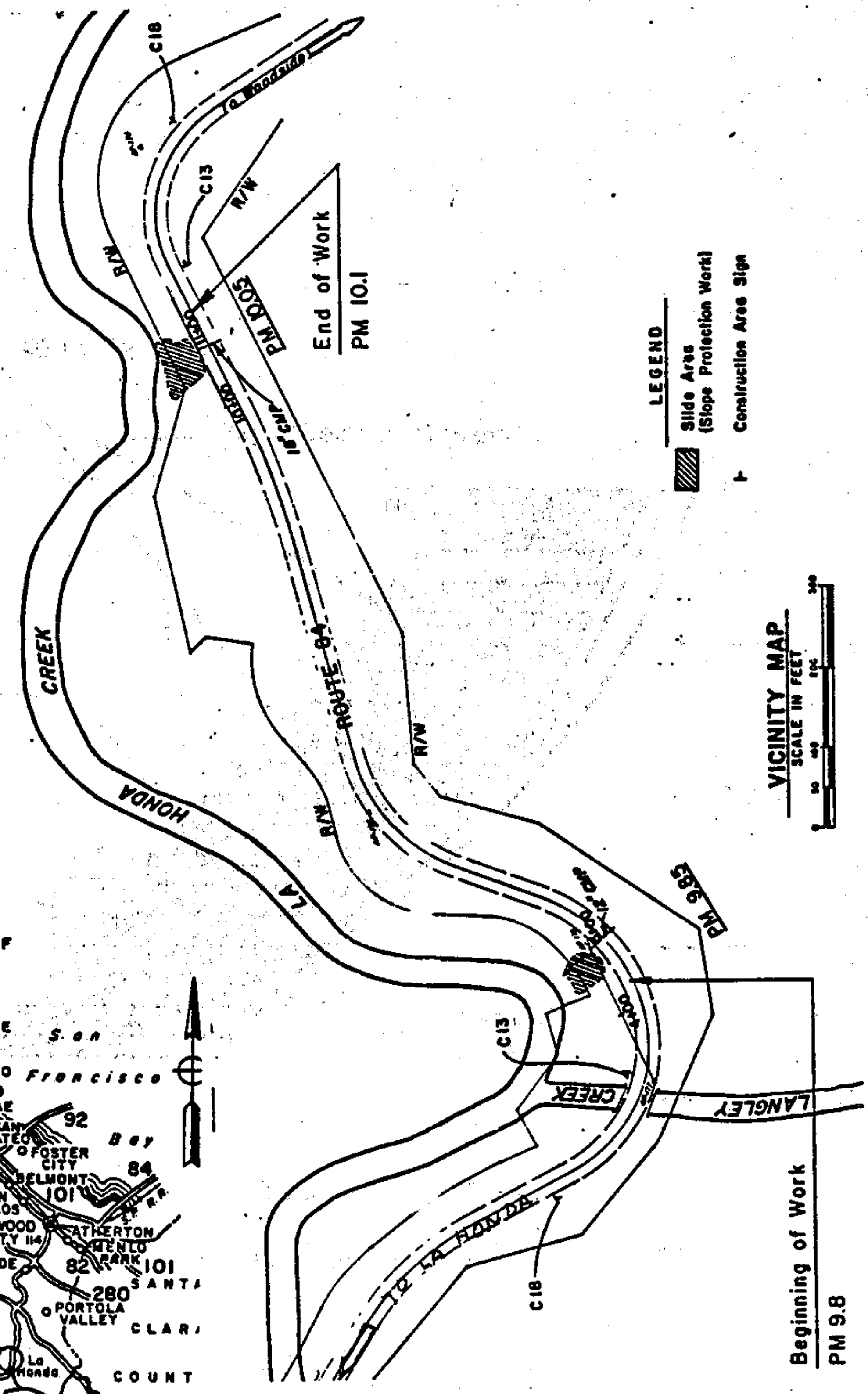
SN-1 through SN-5 = Straddler Nails 1 thru 5 along fogline.
Anchor-1 = Top of anchor rod PVC pipe of upper, east extensometer set.
Anchor-2 = Top of anchor rod PVC pipe of upper, west extensometer set.
Anchor-3 = Top of anchor rod PVC pipe of lower, east extensometer set.
Anchor-4 = Top of anchor rod PVC pipe of lower, west extensometer set.
Rk.Pt.-1 = Painted high point on rock in rip rap.
Rk.Pt.-2 = Painted high point on rock in rip rap.
Rk.Pt.-3 = Painted high point on rock in rip rap.

Table #5. ELEVATION OF REFERENCE POINTS FOR THE FILL AT PM 10.05

Reference Points	Reference Point Elevations Measured in Feet 4/85	8/85	8/85	4/87	Elev. Change
SN-1	1995.71	1995.72	1995.74	lst	+0.02
SN-2	1995.91	1995.92	1995.93	lost	+0.02
SN-3	1996.19	1996.19	1996.17	lost	-0.02
SN-4	1996.16	1996.16	1996.14	lost	-0.02
Top Fill	1996.82	1996.70	lost	lost	-0.12
SE DI	1991.51	1991.49	lost	lost	-0.02
Turn Pt.	1980.14	1980.10	1980.07	1979.41	-0.73 Max.
Toe Pt.	1964.13	1964.16	1964.17	1963.79	-0.34
Rock Pt.	1951.61	1951.64	1951.66	1951.32	-0.29

Reference Point Footnotes:

SN-1 through SN-4 = Straddler Nails 1 thru 4 along fogline.
Rock Pt. = Painted high point on rock in rip rap.



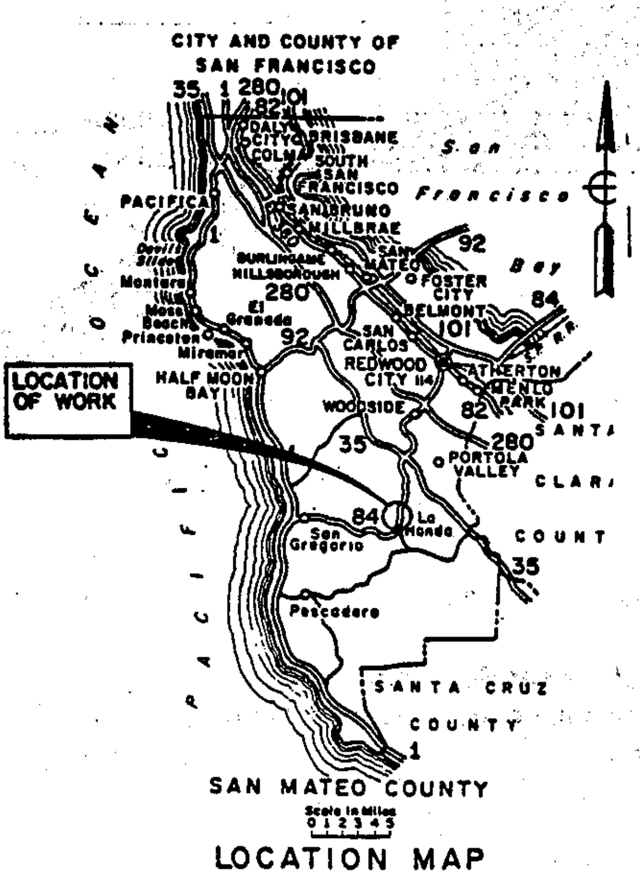


Figure #1.

Location and Site Maps.

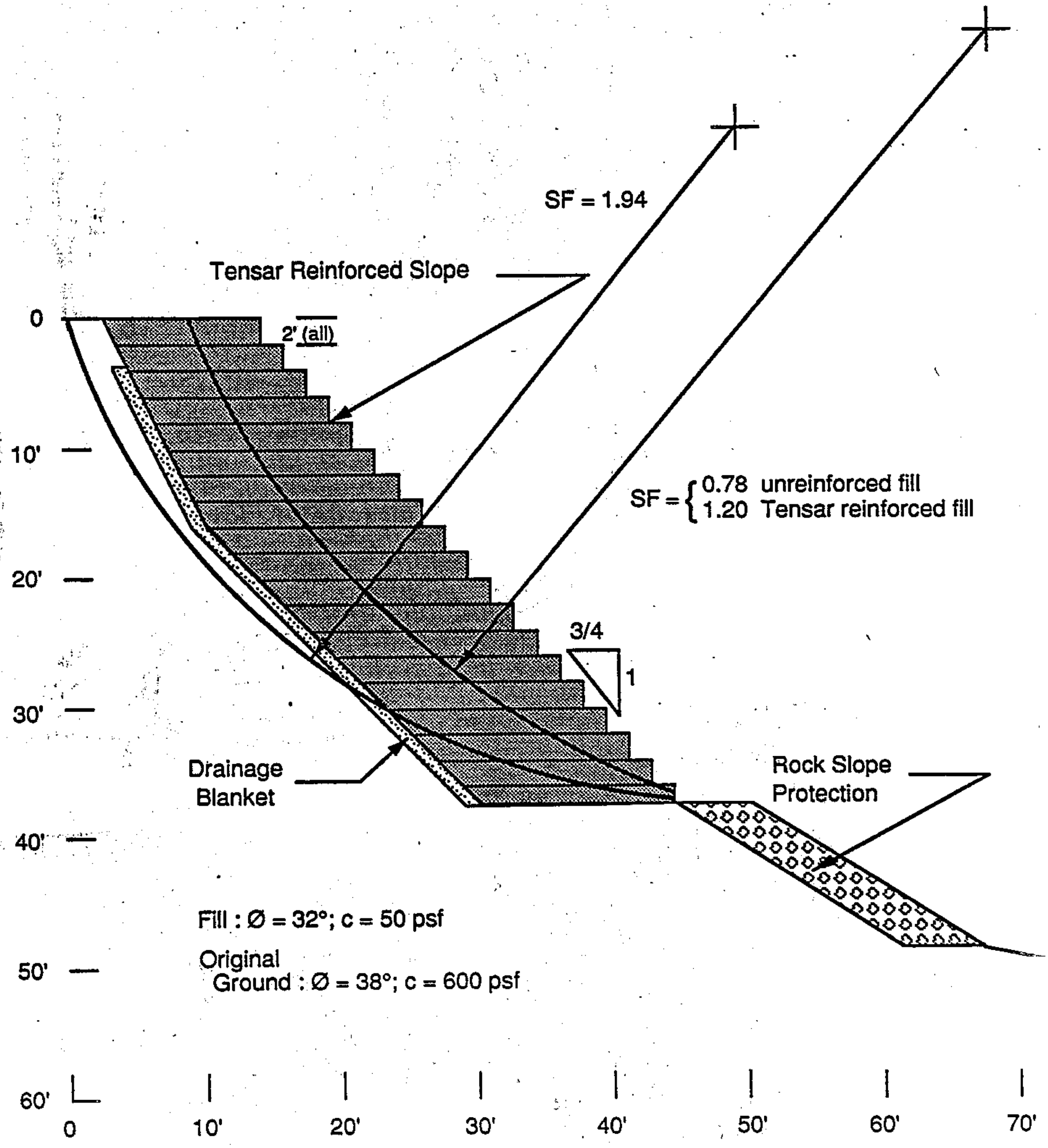


Figure 2 - Cross Section of Tensar Reinforced Slope illustrating critical failure arcs and components of slope design.

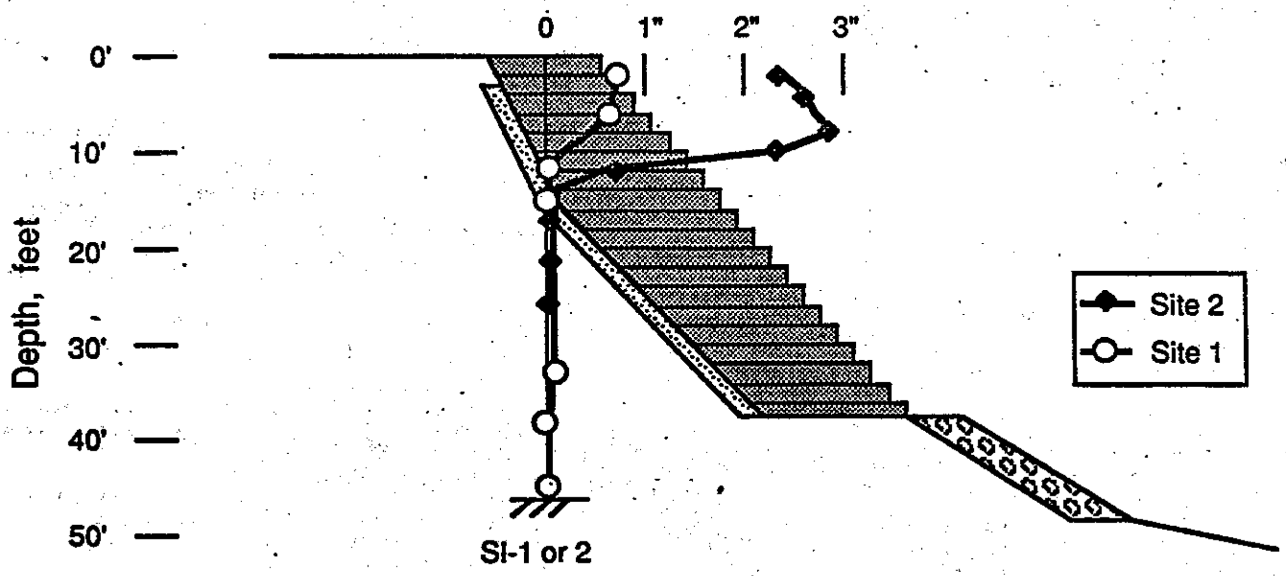


Figure 3a - Cross Section of Tensar Reinforced Slope Showing Final Slope Indicator (SI) Deflection at Site 1 and Site 2.

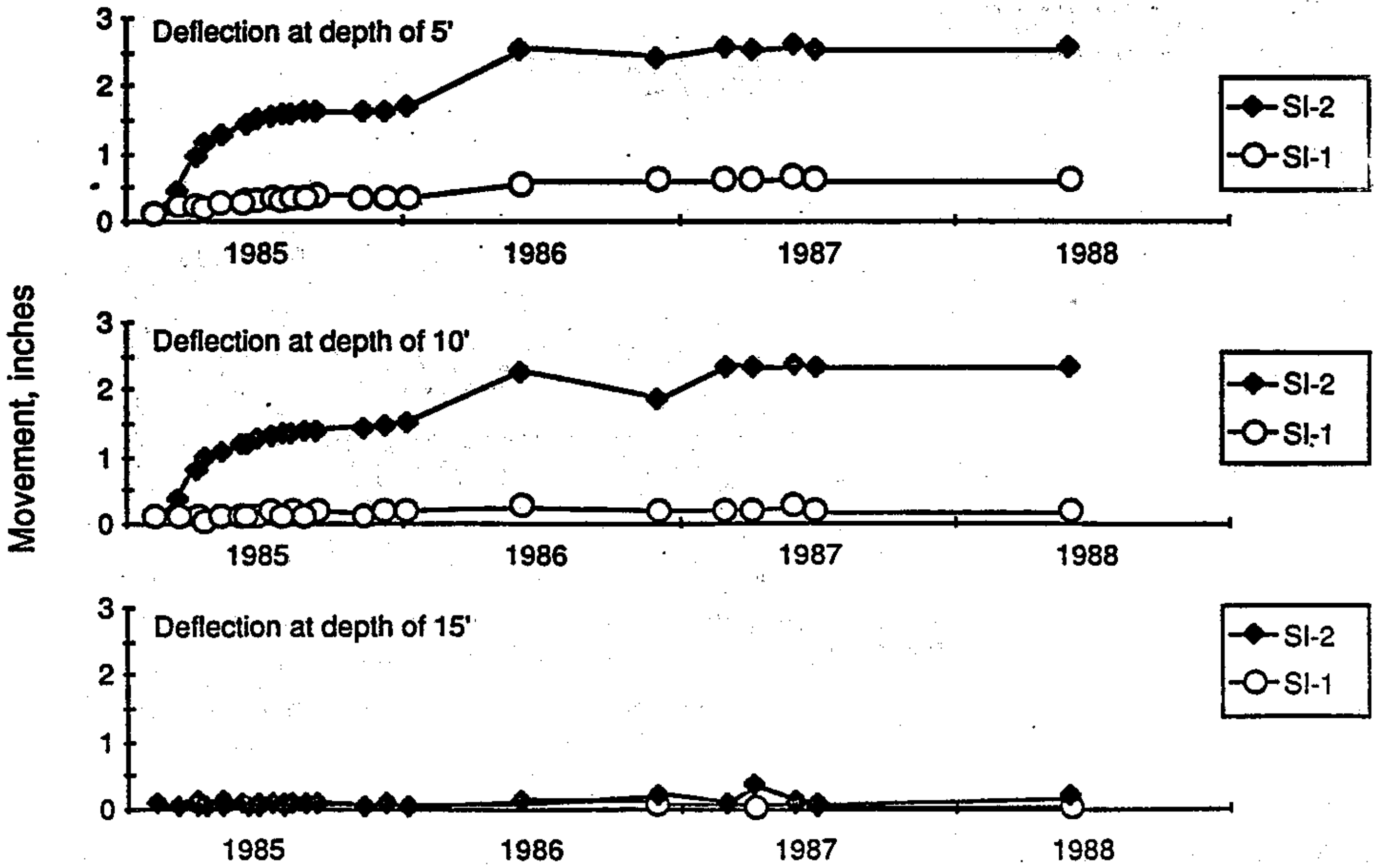


Figure 3b - Time - History of Deflection at Indicated Depths for SI-1 and SI-2.

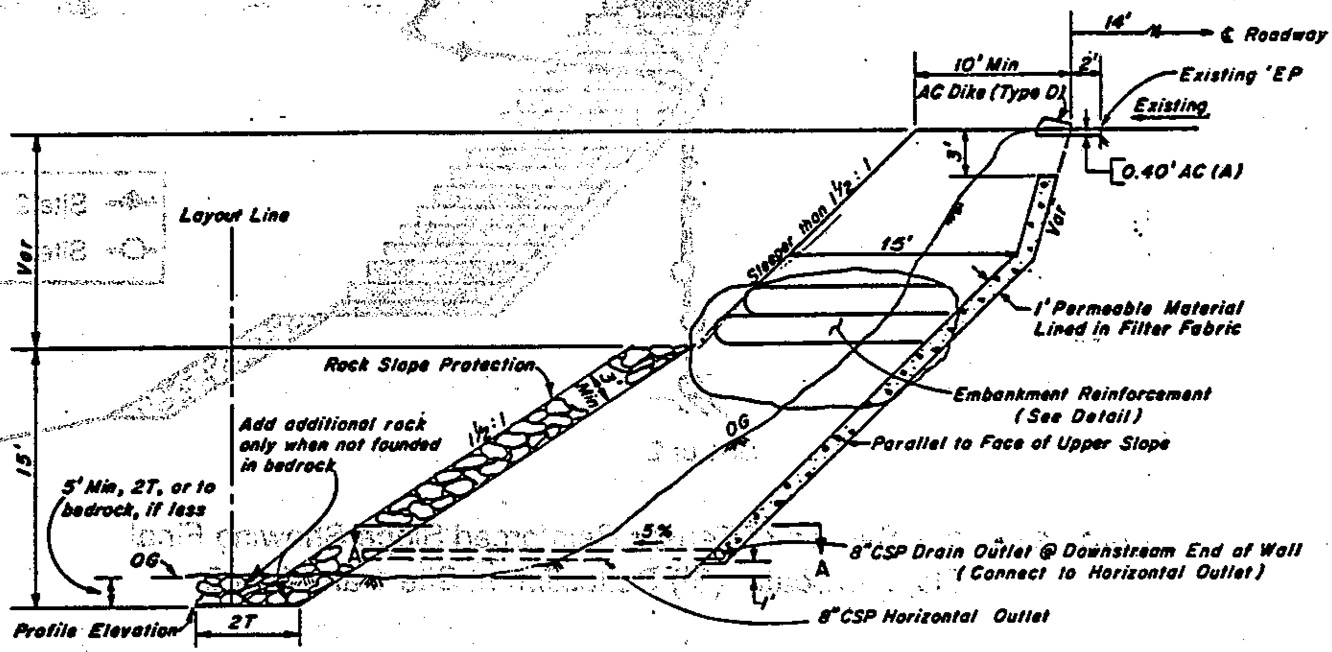


Figure #4a.

Note:
"T" is equal to or greater than 1.5 D where "D" is diameter of nominal rock specified.

TYPICAL CROSS SECTION
No Scale

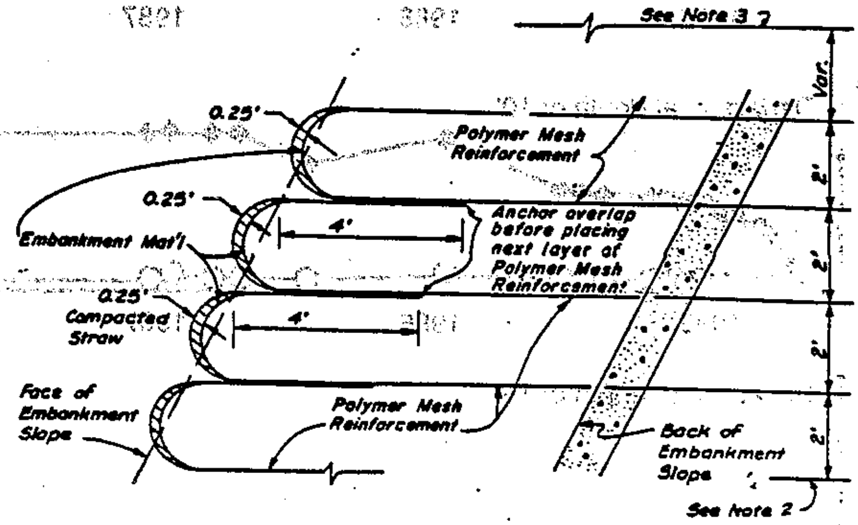


Figure #4b.

EMBANKMENT REINFORCEMENT DETAIL
NO SCALE

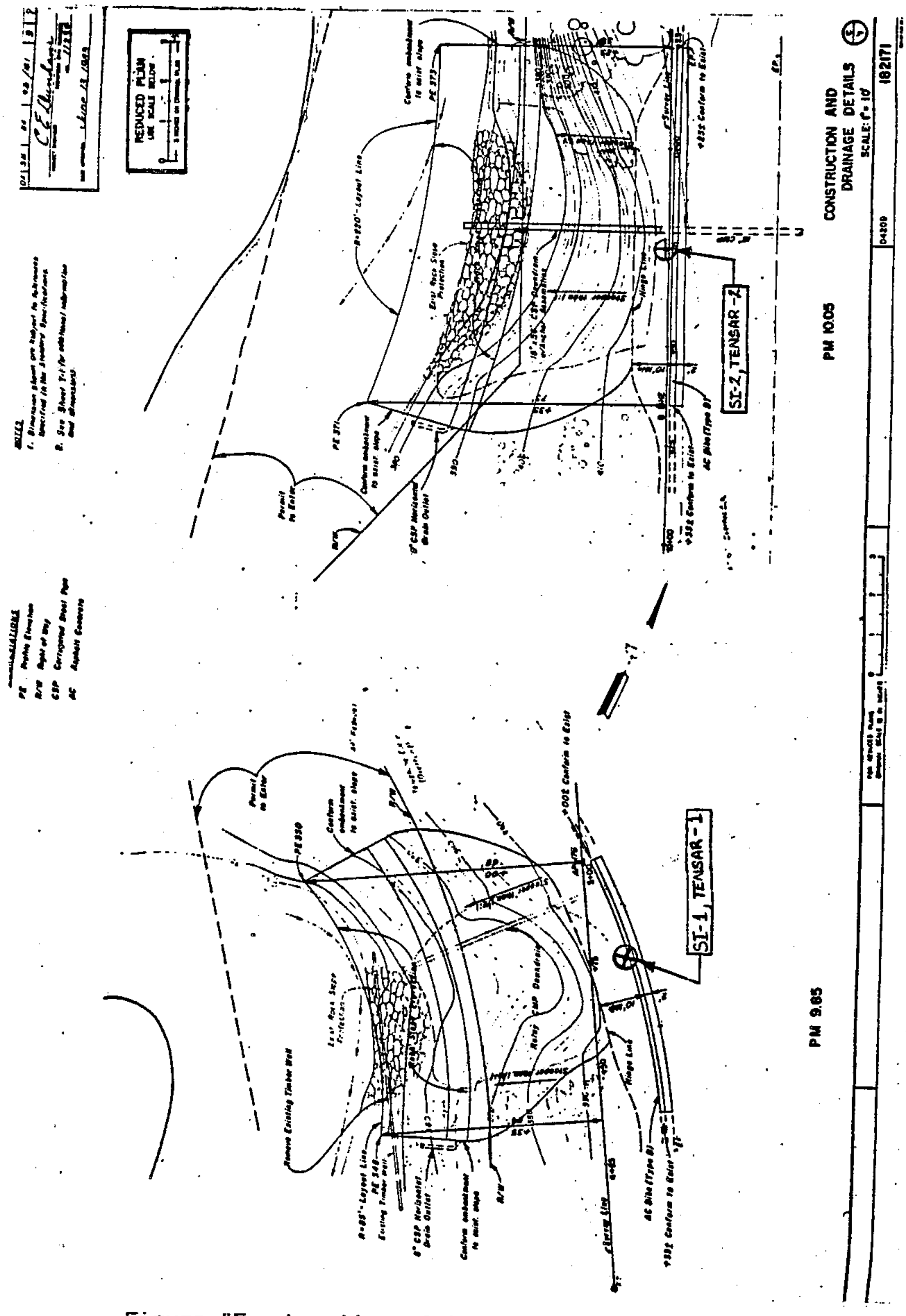


Figure #5. Location of Slope Indicator Sites.

Photograph #01.

Preconstruction site conditions, PM 10.05.

Construction access will be difficult.

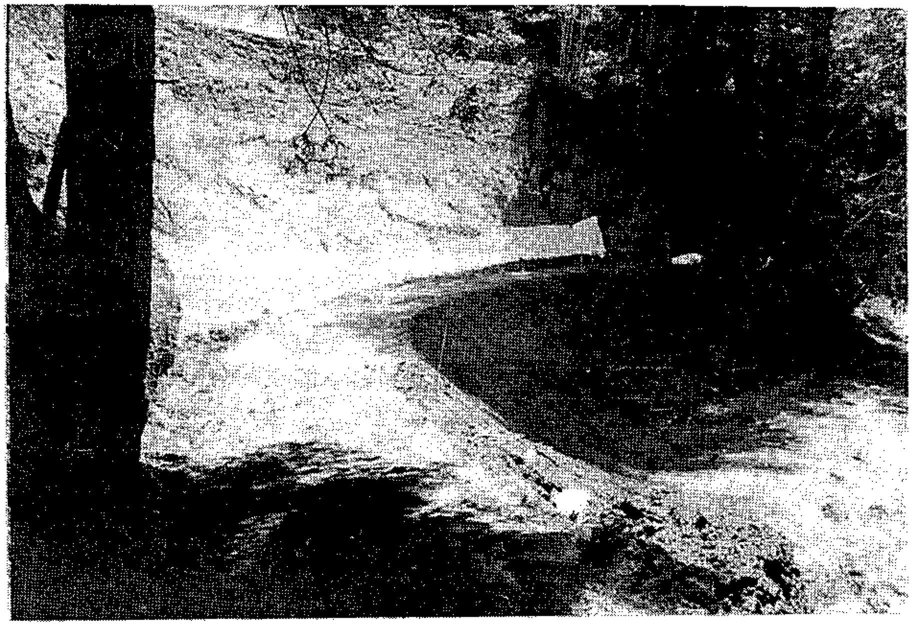
Photograph #02.

Preconstruction site conditions, PM 9.85.

Construction access will be difficult.

Photograph #03.

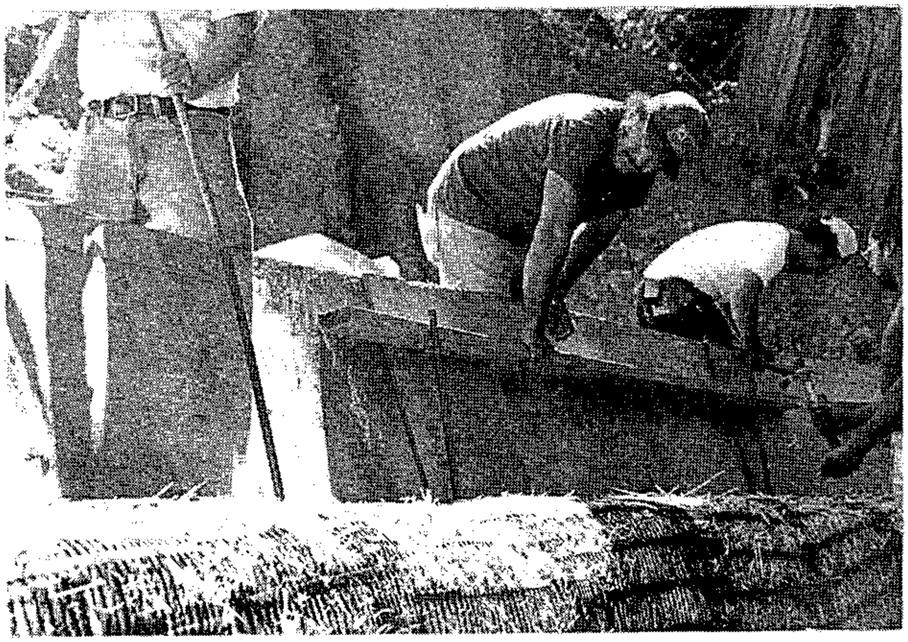
Restricted working room common to both sites.



Photograph #04.

Unreinforced section.

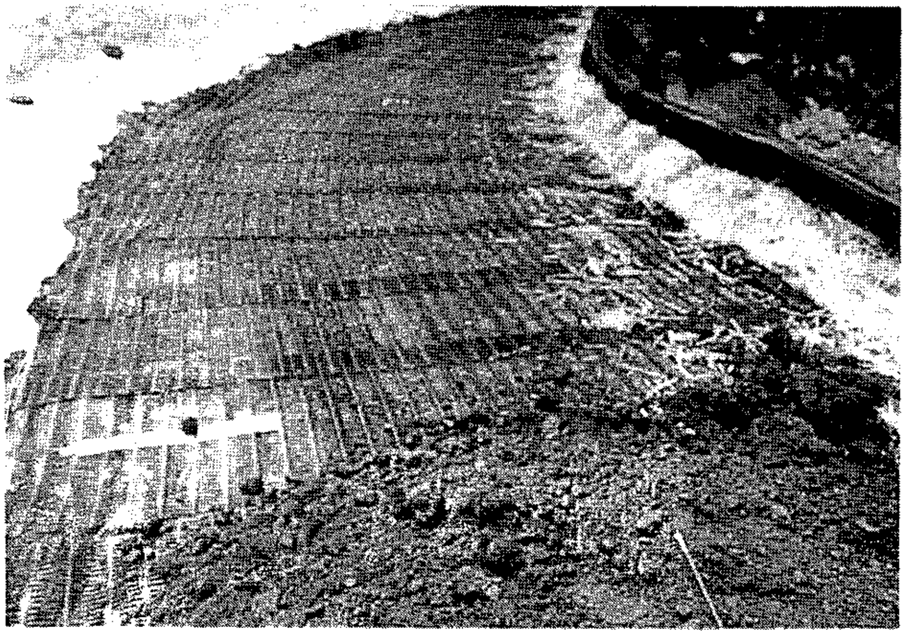
Filter fabric shows between cut slope and fill.



Photograph #05.

Plywood batter.

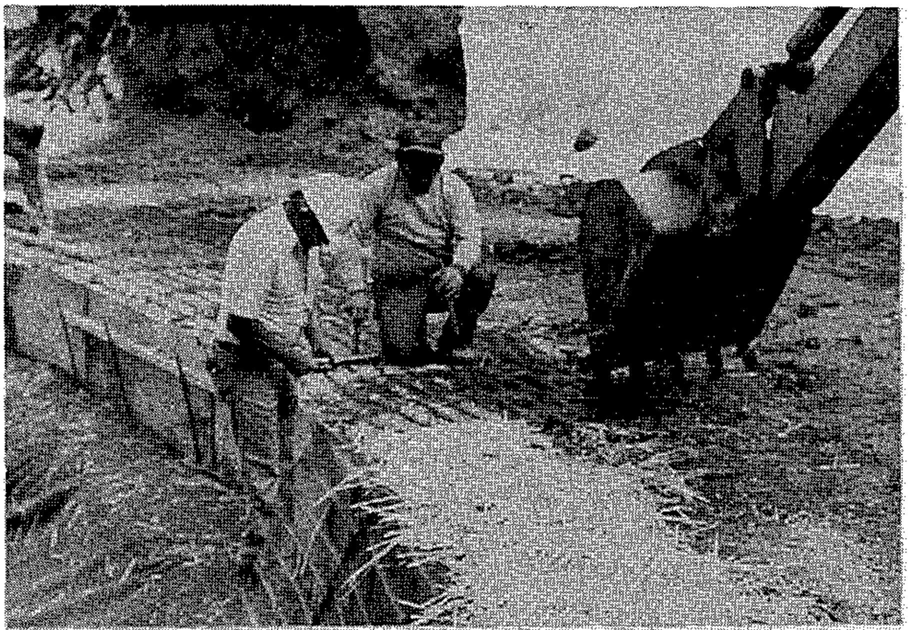
Restrains compacted backfill until the geogrid is lapped and fastened.



Photograph #06.

Backfilling.

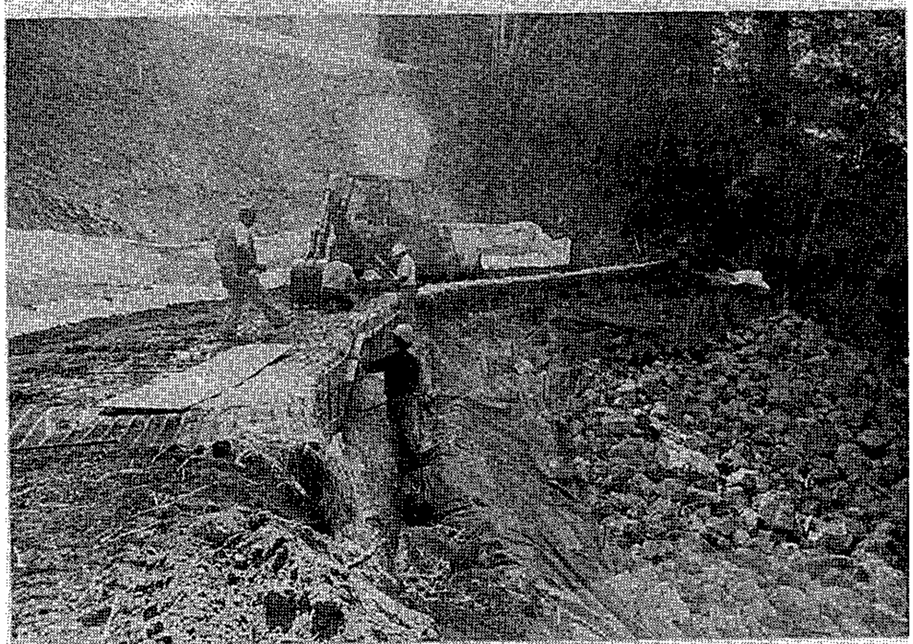
Soil is placed over geogrid and against straw at the batter.



Photograph #07.

Lift completion.

Geogrid is lapped over the top of the step and held by backhoe until secured by hand.



Photograph #08.

Lift completion.

Same as in previous photograph.

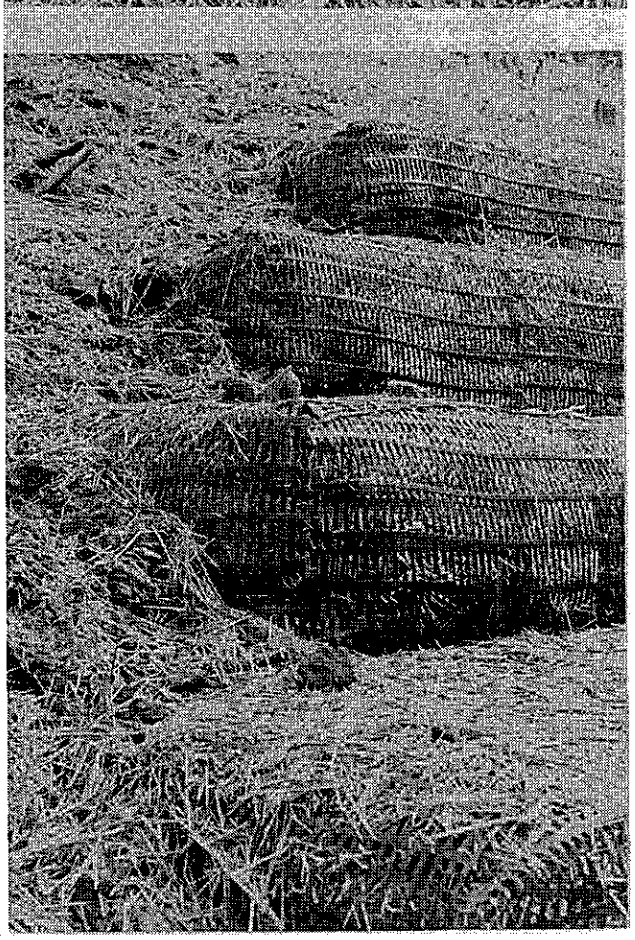
Photograph #09.

Same as in previous photograph.

Photograph #10.

End of step.

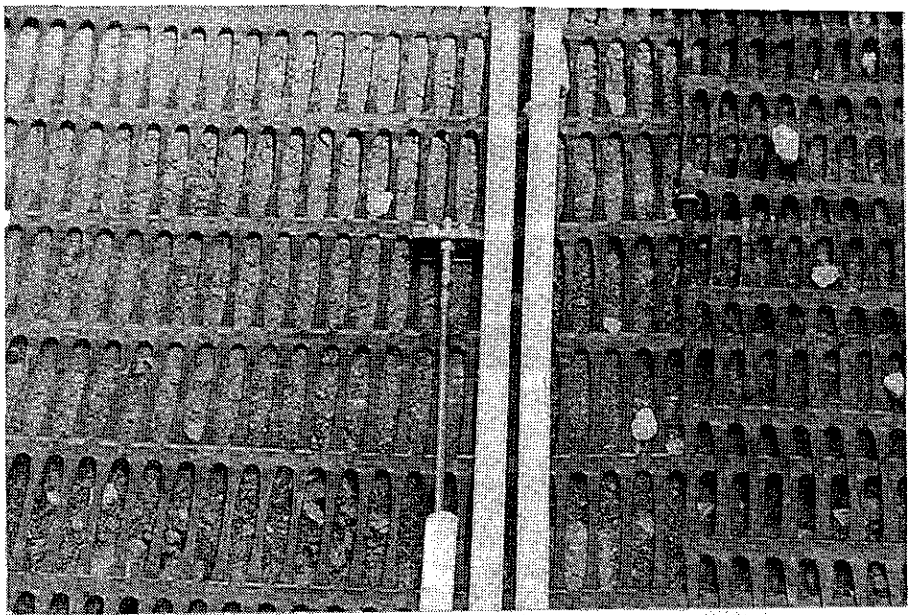
Untucked end of step.



Photograph #11.

End of step.

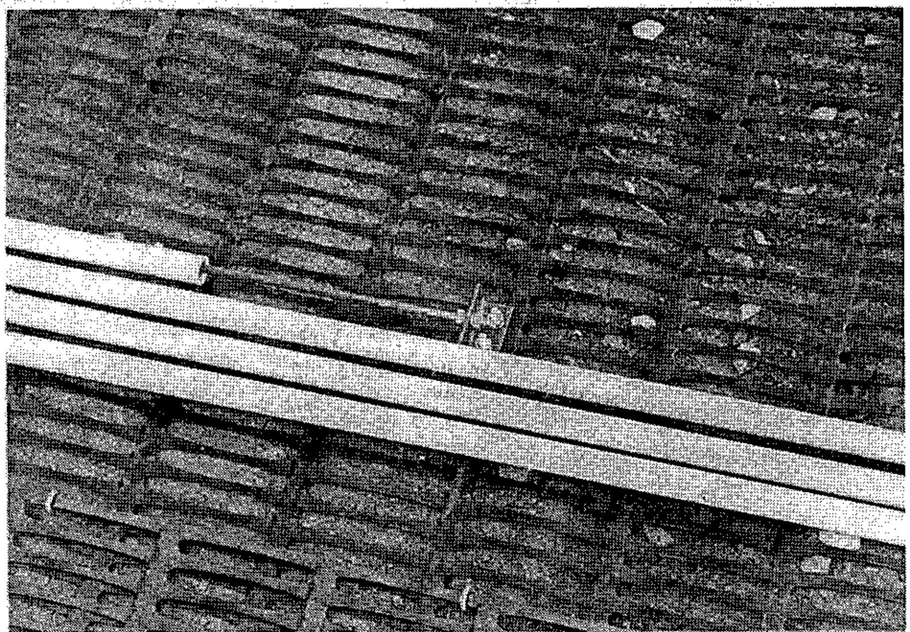
End of step tucked into original ground.



Photograph #12.

Extensometer installation.

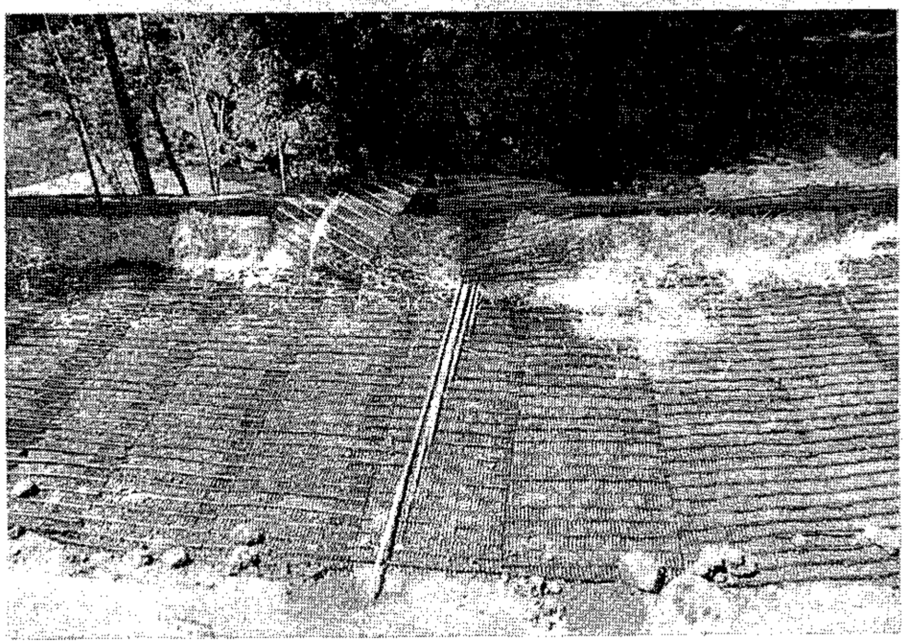
End of extensometer rod secured to geogrid.



Photograph #13.

Extensometer installation.

Same as previous photo.



Photograph #14.

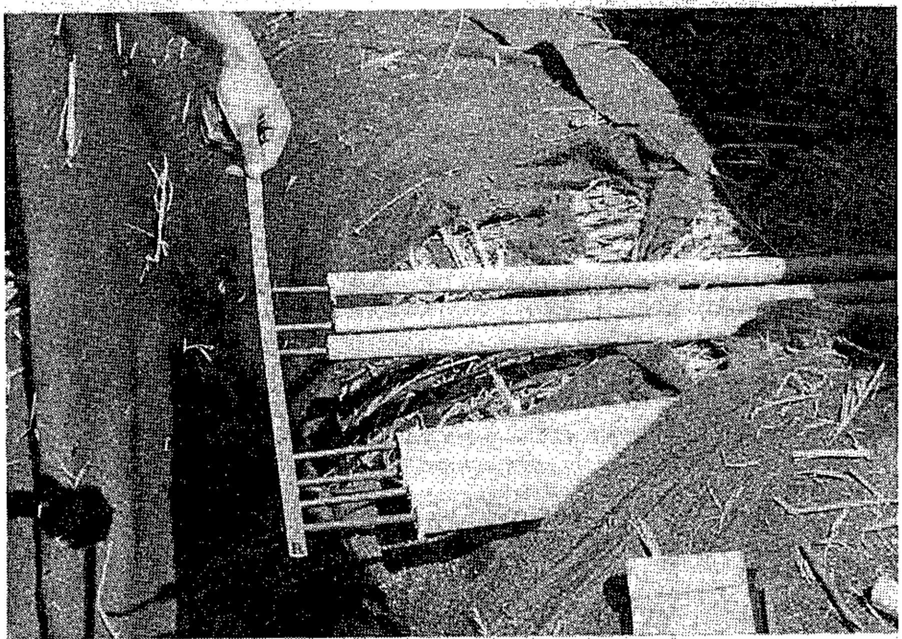
Extensometer installation.

Rods in PVC pass through face of step.

Photograph #15.

Extensometer installation.

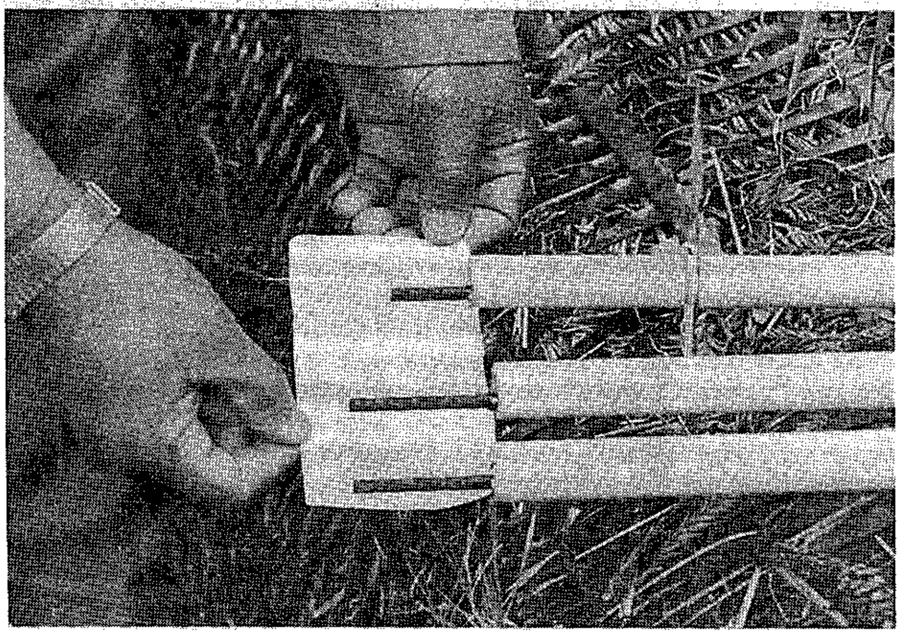
Anchor rod fastened in original ground.



Photograph #16.

Extensometer installation.

Rods cut off evenly to complete installation.



Photograph #17.

Extensometer installation.

Outward movement of rod ends, past end of anchor rod, reflects movement of geogrid and the fill.

Photograph #18.

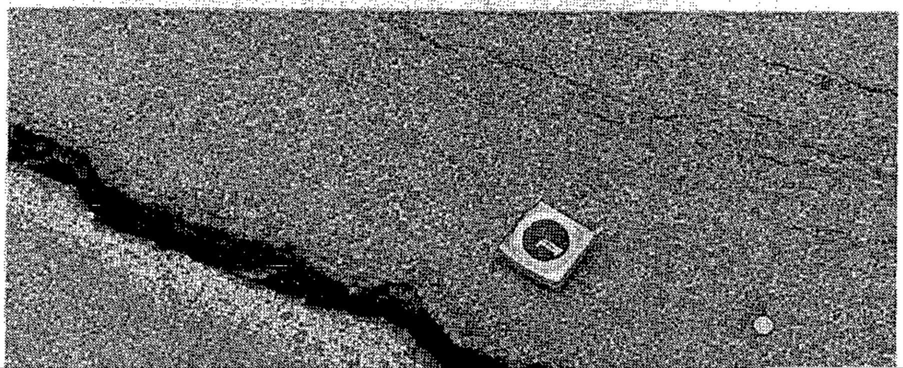
Slope indicator.

Protective cover on top of the slope indicator casing, indicated by arrow.

Photograph #19.

Pavement cracking.

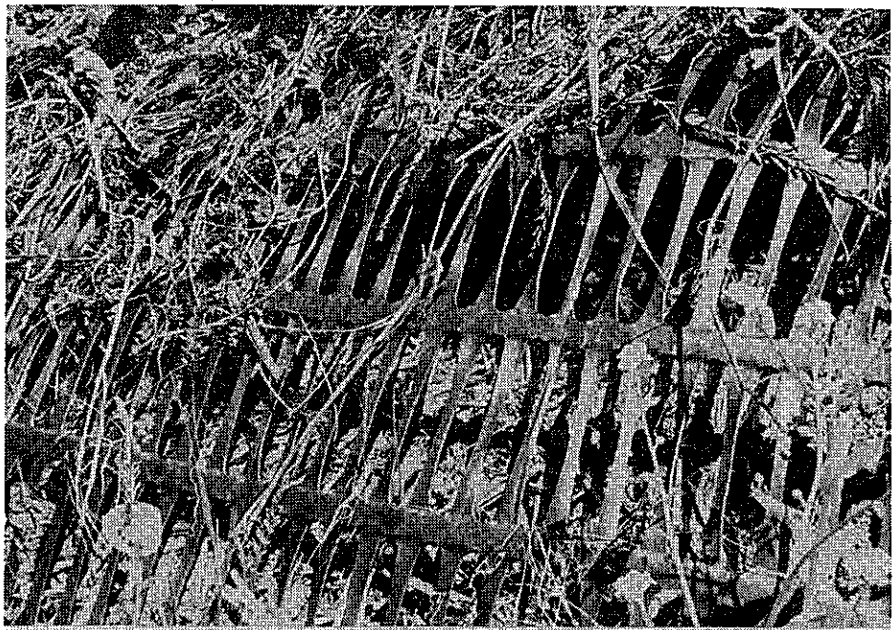
Minor pavement cracking due to settlement.



Photograph #20.

Pavement cracking.

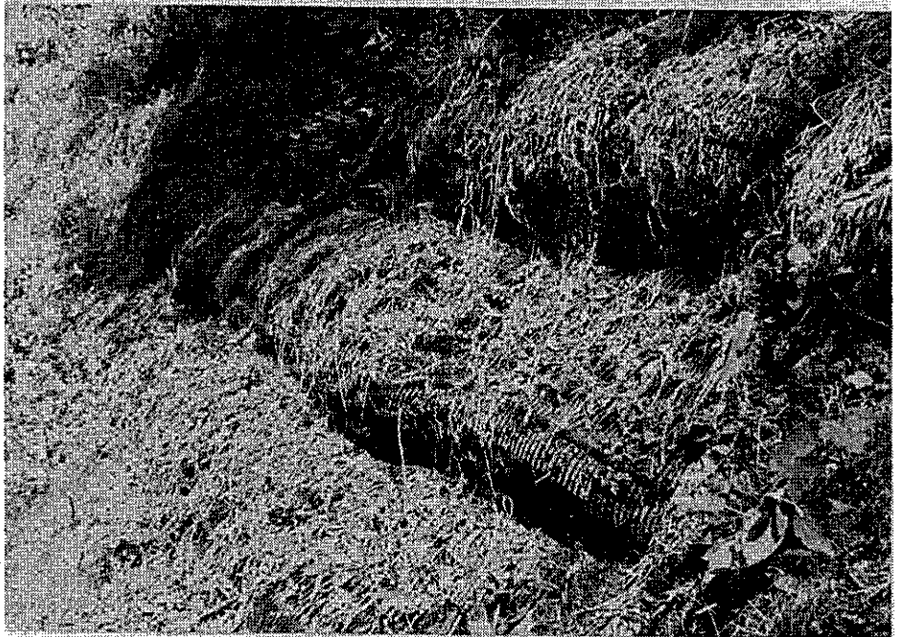
Close-up of pavement



Photograph #21.

Present condition.

Void under geogrid left by decayed straw.



Photograph #22.

Present condition.

Deformation from stepped surface to a more continuous surface.

Photograph #23.

Present condition.

Close-up of above.

APPENDIX A

LA HONDA SLOPE REPAIR WITH GEOGRID REINFORCEMENT

Pages 49 - 52

California Department of Transportation

LA HONDA SLOPE REPAIR WITH GEOGRID REINFORCEMENT

As a result of a series of storms almost unprecedented in their intensity and duration in January 1982, the toe of the highway embankment on Route 84 near La Honda was eroded by the action of a contiguous stream causing a slipout. Site geometry required restoration of the embankment with oversteepened (greater than 1:1) slopes that were strengthened by utilizing Tensar geogrid reinforcement. Embankment design parameters and calculations are presented and design features to mitigate drainage problems and to prevent future erosion at the embankment toe are described. The results of laboratory pullout tests are summarized. Construction, which has been suspended for the winter will be completed the summer of 1984.

INTRODUCTION

As a result of a series of storms almost unprecedented in their intensity and duration beginning in January 1982 and continuing through the past winter, the California highway system sustained severe damage. Consequently, the Department faced significant repair and restoration costs. Extensive damage occurred south of San Francisco on Route 84 near La Honda, California caused by the action of a contiguous stream that eroded the highway embankment causing a slipout. The site geometry and right-of-way constraints required restoration of the original embankment to a slope which was somewhat steeper than that which would assure long-term stability for the soils in the area. The site cross-section diagram (Figure 1) illustrates the critical section where the embankment must be reconstructed. After an initial investigation, the Materials and Hydraulics Engineers recommended the use of earth reinforcement to develop embankment stability. After consideration of several systems, Tensar geogrid was selected. Subsequently, a cooperative research agreement between Caltrans and Netlon was negotiated.

SITE PARAMETERS AND BACKGROUND

The slipout site is 70 m in length requiring slopes varying from 1.5:1 to approximately 1:1. The streambed is 14 m below the freeway grade and 11 m laterally from the hinge point on freeway grade at the critical cross-section. Access to the area is limited. The water table fluctuates up to 3 m and corresponds with changes in the stream elevation. Acquisition of additional right-of-way was not possible.

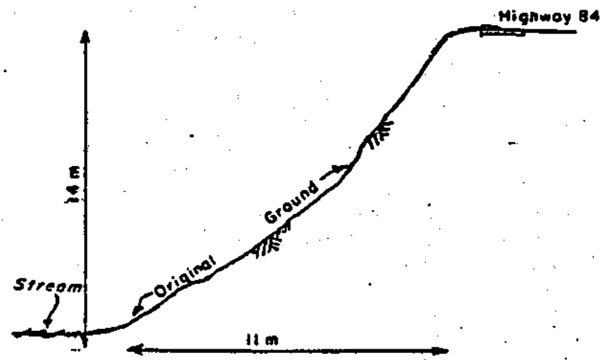


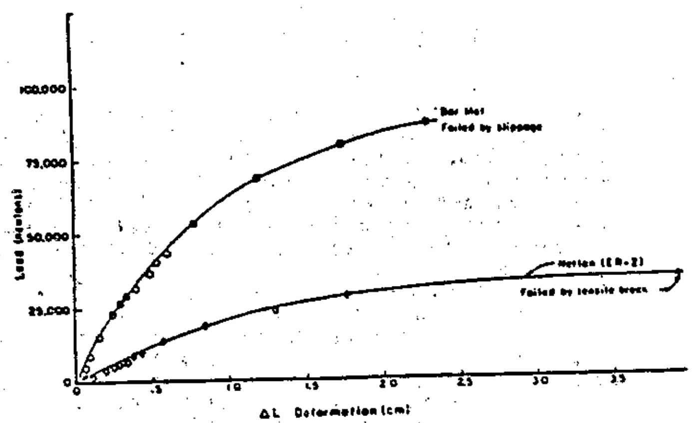
Fig. 1 Cross-section Diagram

The initial storm damage repair report called for rock slope protection 4.5 m high on a 1.5:1 slope placed at the embankment toe. Maintenance forces cleared the streambed of log jams and debris and placed 376,500 kg of rock slope protection as an interim repair. Permanent repair required rebuilding the upper embankment to slope ratios as steep as 0.9:1. Earth reinforcement would be necessary for reconstruction. The Caltrans' Transportation Laboratory initiated design of the reinforced embankment utilizing slope stability analysis and information generated from previous large scale laboratory pullout tests conducted on Tensar ER-2 (renamed Tensar SR-2).

PULLOUT TESTS

Large scale laboratory pullout tests were performed in 1980 on Tensar ER-2(1). The test apparatus consisted of a rigid steel box 46 cm deep, 92 cm wide and 137 cm long in which soil is compacted half way, the geogrid material placed on this layer, and the remainder of the box filled with soil and compacted. A hydraulic ram located above the test box simulates overburden loads up to an equivalent of 15 m of earthfill. A horizontally positioned hydraulic ram attached to the geogrid provides the pullout force. Displacement is adjusted to maintain a controlled strain rate of approximately 2%/min. The pullout tests were performed on Tensar ER-2 in the direction the fabric is drawn from the roll.

Utilizing decomposed granite from an unspecified site as fill (ϕ equal to 35°) and imposing an overburden load equal to 34.5 kPa, the geogrid was pulled to failure. The Tensar ER-2 failed in tension outside the soil block (Plates 1 and 2) at a load of 44,000 newtons/meter indicating design would be limited by the geogrid material's maximum tensile strength. Load versus deformation curves were developed from the pullout tests including a comparison between Tensar ER-2 and bar mesh reinforcement (Graph 1). Bar mesh reinforcement of soil has been used by Caltrans to strengthen wall supported embankments(2). The bar mesh (constructed from 0.95 cm diameter reinforcing bar welded to form 10 cm by 20 cm spacings) has sufficient steel to preclude tensile rupture and force a slippage failure within the soil block. Thus, the bar mat fails in pullout producing a cone shape failure near the soil face. From the graph, the ultimate strength of the Tensar can be obtained and used in design calculations.



Graph 1: Load Versus Deformation Characteristics of Bar Mesh & Tensar ER-2

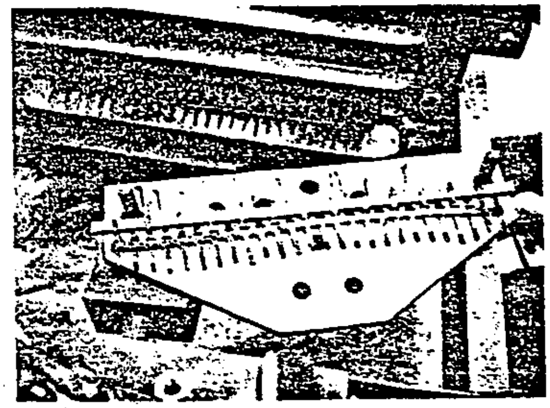


Plate 1 Tensile Break, Pull Section

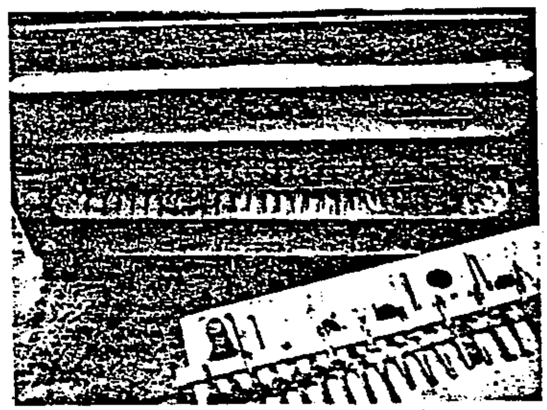


Plate 2 Tensile Break, Face Plate

DESIGN

Computer slope stability analysis was used to determine the safety factor of the reconstructed embankment without reinforcement. From triaxial compression testing of samples of the native soil, properties at the La Honda site were determined to be:

$$\text{Cohesion} = 2.5 \text{ kPa}$$
$$\phi = 32^\circ$$

These parameters, along with site dimensions, were input into SOILX, a circular slope stability program utilizing the modified Bishop technique. From the computer analysis, a minimum safety factor of 0.78 was calculated for the unreinforced embankment. Because an overall safety factor of 1.2 or greater was desired, additional resisting moment due to the soil strength increases from the reinforcement had to be quantified and new safety factors generated.

La Honda Slope Repair With Geogrid Reinforcement

Utilizing the computer generated overturning moment, and friction and cohesion resisting moments, the required reinforcement to increase the resisting moment later was determined. The following equations illustrate the calculations used for estimating safety factor (S.F.) increases as a result of the added reinforcement.

$$S.F. = \frac{\text{Resisting + Tensar Moment}}{\text{Driving Moment}} \quad \ldots\ldots 1)$$

$$1.2 = \frac{2.01\times10^6 \text{ newton-meters} + \bar{a}\cdot\Sigma T_n}{2.57\times10^6 \text{ newton-meters}} \quad \ldots\ldots 2)$$

$$\bar{a}\cdot\Sigma T_n = 1.2\cdot(2.57\times10^6)-2.01\times10^6 = 1.07\times10^6 \text{ newton-meters} \quad \ldots\ldots 3)$$

where: 2.01×10^6 (nt-m) = Resisting moment @ S.F. = .78

2.57×10^6 (nt-m) = Driving moment @ S.F. = .78

$\bar{a}\cdot\Sigma T_n$ = Total Tensar moment

The coordinates of the failure arc and the location of the centroid of the reinforcement are used to determine the distance ($\bar{a}$) to the centroid of reinforcement. In this case, $\bar{a}$=14.3 meters (Figure 2).

$$\text{Tensar moment} = \bar{a}\cdot\Sigma T_n = 1.07\times10^6 \text{ newton meters} \quad \ldots\ldots 4)$$

$$T_n = \frac{1.07\times10^6 \text{ newton meters}}{14.3 \text{ m}} = 74720 \text{ newtons} \quad \ldots\ldots 5)$$

The allowable working strength of the Tensar was limited to 6.670 newton/meters (15% of the ultimate strength). Knowing the working tensile strength contributed per meter, the number of reinforcing layers was determined.

$$\frac{74{,}720 \text{ newtons}}{6{,}670 \text{ newtons/layer}} = 11.2 \text{ layers} \quad \ldots\ldots 6)$$

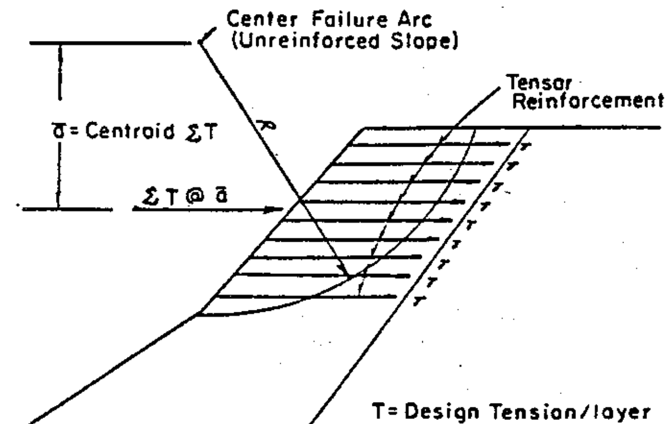


Fig. 2 Determining the centroid of Tensar Moment

Based on these calculations, vertical spacing of the Tensar was standardized at 0.6 meter. Circular failure arcs were plotted to assure that the embedment depth of the reinforcement was sufficient to preclude pullout of the Tensar. Figure 3 illustrates the geometrics of the critical cross-section. The embankment is approximately 14 m high. The lower 4.5 m has a slope ratio of 1.5:1 and is covered with 1 meter of rock slope protection to prevent water scour. The slope ratio in the upper reinforced portion of the embankment is steeper than 1:1. Permeable material lined with filter fabric is placed at the interface of the original ground and the reconstructed embankment. The permeable blanket drains into a horizontal outlet pipe located at the embankment base. The Tensar geogrid extends from the permeable material to the slope face.

Each layer of reinforcement will be folded back a minimum of 1.5 m and anchored in place. The face of the embankment is lined with compacted straw. The total amount of Tensar SR-2 required to complete the slope is 6000 square meters.

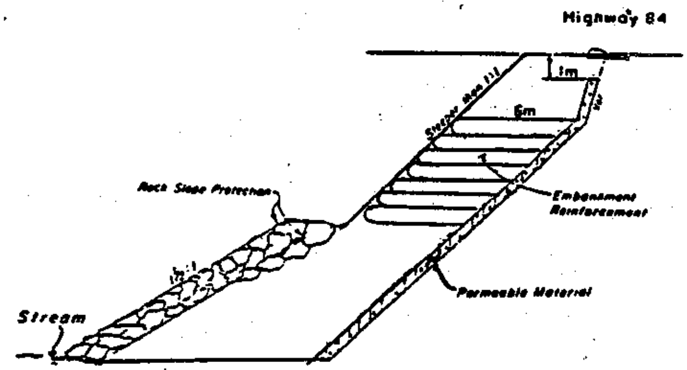


Fig. 3 Final Design Geometrics

INSTRUMENTATION

In order to monitor the stability of the reinforced embankment and the performance of Tensar SR-2, instrumentation was incorporated in the fill.

The instrumentation placed in the embankment includes:

1. One Inclinometer installed through the reinforced embankment structure.

2. Extensometers at three levels to monitor lateral movement and internal strains within the reinforced embankment.

3. Survey reference points at the hinge line and toe of the embankment to monitor vertical and horizontal surface deformations.

ALTERNATIVE REINFORCEMENT

Before reaching an agreement with Netlon, tire sidewall reinforcement was considered at the La Honda site. Tire sidewall reinforcement consists of recycled tire sidewalls hooked together with steel rods(3). The system's material costs are low, but construction is labor intensive. The embedment depth necessary to ensure slope stability was equivalent to that necessary to achieve slope stability with Tensar SR-2. Due to variations in limiting lengths of reinforcement, a total of 4800 m² of tire sidewall reinforcement was considered sufficient to stabilize the embankment to the desired safety factor.

COST COMPARISON

Comparing the cost of Tensar SR-2 to the cost of the required amount of tire reinforcement revealed a substantial cost savings for the Tensar project. Bar mat cost comparison is included, though actual design was not initiated.

Tensar Grids
6000 m^2 @ $4.50/$m^2$ = $27,000
U.S. Currency 1982

Tire Reinforcement
4800 m^2 @ $13.45/$m^2$ = $65,000
U.S. Currency 1982

Bar Mat Reinforcement
2060 m^2 @ $67.30/$m^2$ = $138,600
U.S. Currency 1982

By using Tensar geogrid reinforcement, Caltrans was able to realize the greatest cost savings.

CONSTRUCTION

Due to inclement weather and restrictions in the bid process, the construction at La Honda has been shut down until the spring of 1984. When construction resumes and the project is complete, Caltrans will publish research results of the slope repair at La Honda using Tensar geogrids.

CONCLUSIONS

As a result of pullout tests and design cost analysis, Caltrans has found that geogrid fabrics can be an economical earth reinforcement system. The long-term benefits realized by using geogrids in corrosive environments are considerable. Though not as strong in tension as other types of reinforcement, the La Honda project should demonstrate that satisfactory results can be obtained with geogrid reinforcement at a cost savings.

ACKNOWLEDGEMENTS

The authors would like to thank the following people for their service and technical assistance in completing this paper: Ken Jackura, Darla Bailey, Morris Tatum and Bernie Hartman.

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1. Hannon, Joseph B. and Pete Mundy (1980). Pullout Tests on Tensar ER-2, Transportation Laboratory.

2. Forsyth, Raymond A. and Joseph B. Hannon (1984). "Performance of an Earthwork Reinforcement System Constructed with Low Quality Backfill," prepared for presentation at the 63rd Meeting of the Transportation Research Board, Washington, D.C., January.

3. Yee, W. S. (1979) "Fill Stabilization Using Non-Biodegradable Waste Products - Phase II," Final Report No. FHWA/CA/TL-79/22, Caltans Laboratory, Sacramento, California, November.

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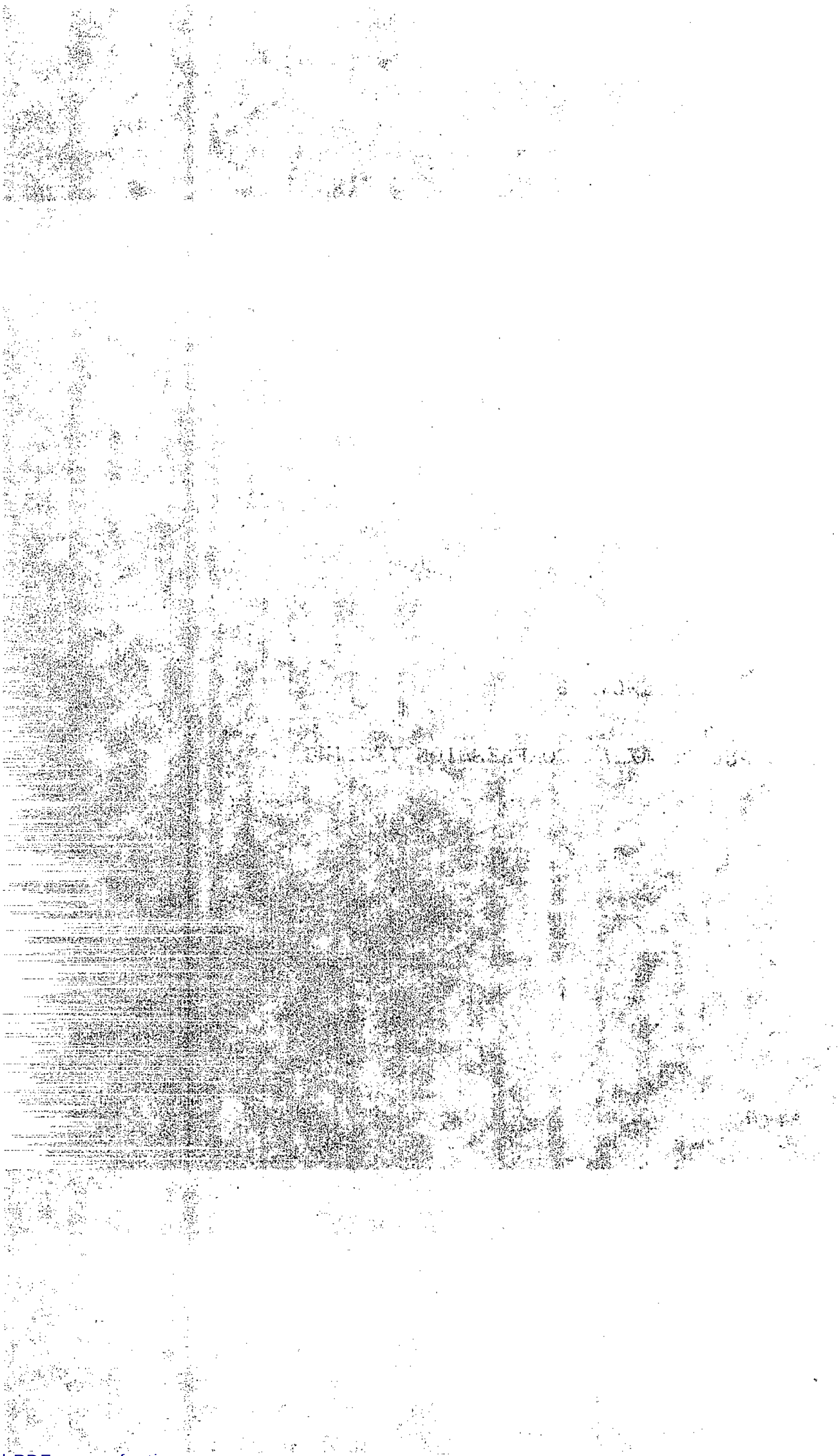
5. Ingold, T. S. (1983). "Laboratory Pull-Out Testing of Grid Reinforcements in Sand," Geotechnical Testing Journal, GTJODJ, Vol. 6, No. 3, September, pp. 101-111.

APPENDIX B

SOIL SAMPLING AND TRIAXIAL COMPRESSION TESTING

Pages 53 - 54



ORNIA DEPARTMENT OF TRANSPORTATION
RICT 4 MATERIALS

ORING RECORD

Location SLIPOUT @ P.M. 9.8
Dist. 04 Co. SM Rt. 84 Sec. Cont. 04203 – W.O. 183171
Ft., Right, Left P.M. Line Sta.

ELEV. Datum | Surface | Dia. of Sampler 1" | Wt. of Hammer 25 # | Date 3-8-82 | Job No. 6393 | Page 1 OF 1 | Boring No. S-1

Sample No.	Sampled	Depth	Elev.	Core Catcher Used	% Rec.	Retained Sample Core Box No.	No. Tubes	No. Jars
	From							
	To						Core Length	
	From							
	To						Core Length	
	From							
	To						Core Length	
	From							
	To						Core Length	
	From							
	To						Core Length	

Rig Used
Type of Sampler
Type of Point | Regular | Extension
Sample Nos.
Type of Core Barrel
Type Bit Used | Number | From | To

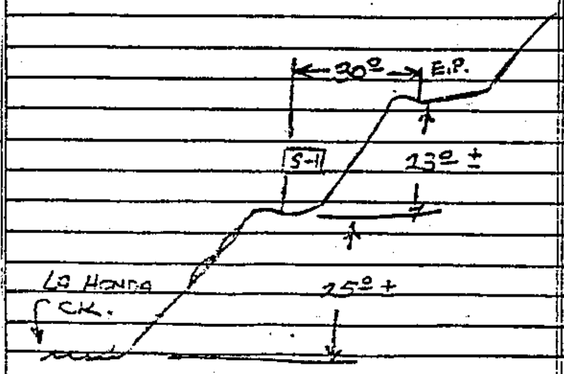
GROUND WATER DATA

Time	Depth to Water	Depth to Bot. Bor.	Time	Depth to Water	Depth to Bot. Bor.
@Comp.	13.0	15.5			

REMARKS

SOIL TUBE TAKEN FOR SLIDE INVESTIGATION.

SOIL TUBE LOCATED IN APPROX. CENTER OF SLIDE MASS.
HAND ELEV. FROM HOLE TO ROADWAY = 23.0±



NOTES:

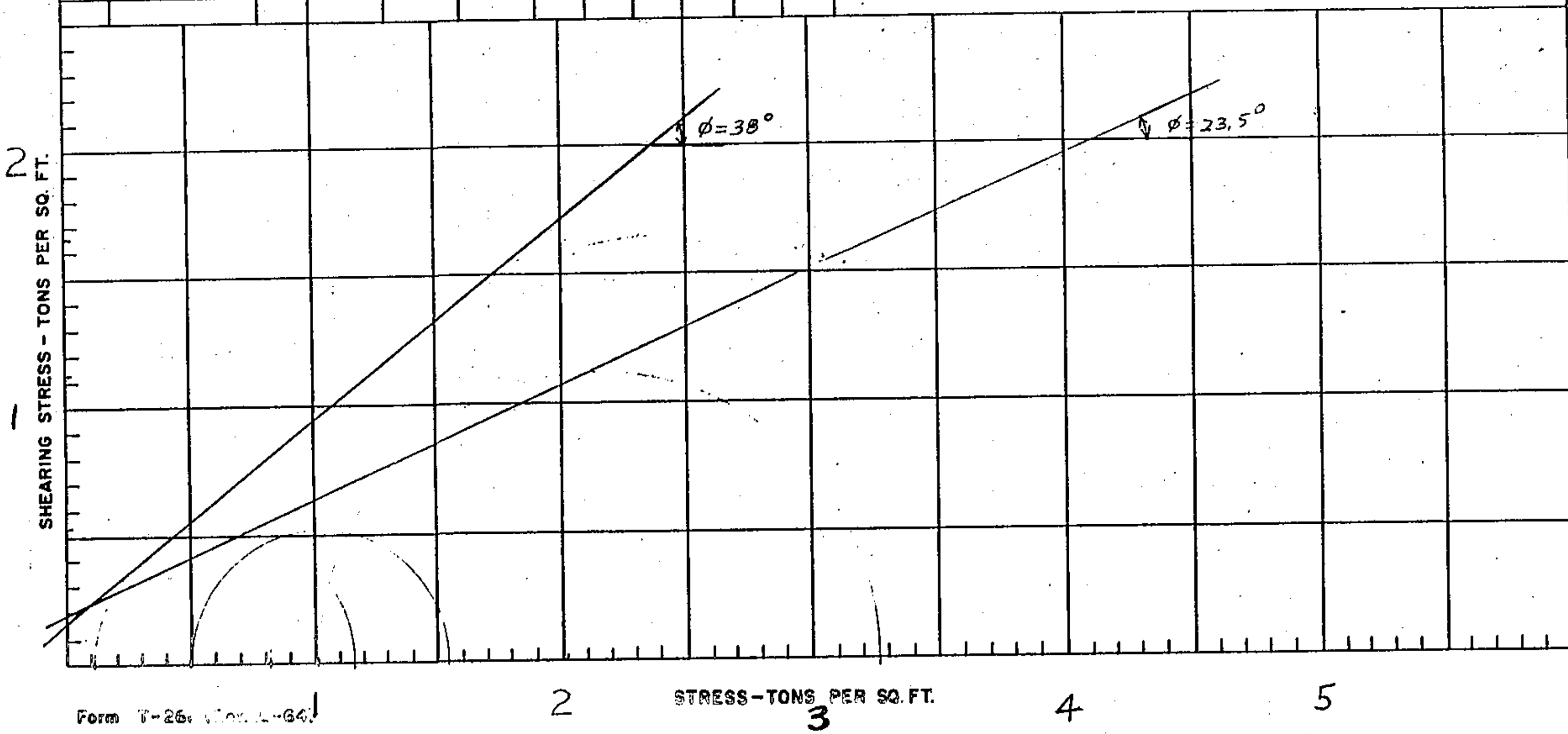
Depth	Per Ft.		Tubes	Wet Wt. per cu. ft.	Moist. % dry wt.	LOG OF MATERIAL
0				—	28.0	GRY. BRN. SI. CL.
1	P	a				± 30% ANG. RK. TO
						3/4", V. MOIST →
2	P					WET IN SPOTS.
						(SLIDE MAT'L)
3	11					
4	10					MOSTLY GRY. BRN.
						SI. CL. W/ SOME
5	7	b		112	20.1	SOFT SHALE FRAG.
						MOIST, STIFF, P.S.
6	15					(O.G.) (UNDISTURBED).
7	29					
8	51					
						MOSTLY BLK. WEATHERED SHALE W/ SOME
9	48	c		—	21.5	GRY. BRN. SI. CL. BINDER.
10	67					LOOSE, MOIST, N.P.
11	120					
12	51					BL. GRN. & GRN. GRY.
						SI. CL. W/ TRACE
13	25					F.G. SD., MOIST
		d		116	30.2	V. STIFF, P.S.
14	53	e		—	17.6	
15	66					SAME BUT W/
						CSE. ANG. RK.
16	173					(F.G. SD. ST.)
						BOTT. @ 16.0

MATERIALS & RESEARCH DEPARTMENT

TRIAXIAL COMPRESSION TEST DATA

Job No. 04-182171		Boring No. 84 1295-1,2,3	
Dist. 04	Co.	Rte.	Sec.
Location LA - HONDA			

Sym.	Sample Ident.	Type Test	σ_3 T.S.F.	$\sigma_1-\sigma_3$ T.S.F.	Wet Unit Wt.	% Moist.	Grain Size Analysis Gr.	Sd	Si	Cl	P.I.	Coh. = 800 lb/ft² ϕ = 23.5° Degrees	Remarks
3997	84-1295-1	CUe	0.50	1.16									
3992	84-1295-2	11	1.01	2.26									
3996	84-1295-3	11	2.02	3.29								σ_3' 0.12	$\phi = 38°$
												0.50	
												0.73	c - 600 lb/ft³
				0.53									
				1.13									
				1.65									



Form T-26 [illegible]

APPENDIX C

SLOPE INDICATOR DRILLING LOGS

4 DL 320 (7/78)

DEPARTMENT OF TRANSPORTATION

POWER BORING LOG

DISTRICT 4

CO. SM RTE. 84 P.M. 9.82 AUTH. NO. ____	DRILL RIG. 484	JOB NO. 6393
LIMITS: SLIDE CORRECTION @ P.M. 9.82 & 10.05	BORING DIA. 8" AUGER	BORING NO. P-1
OWNER STATE ELEV. ____ DATUM ____	PARTY CHIEF NAKAMURA	PAGE 1 OF 1
____ LINE, STATION ____ ____ FT. LEFT, RIGHT	DRILLER SHANBROOK	DATE 1-23-85

CASING LENGTH 48.0

TYPE PLS. S.I. DIA. 2.75

BACKFILL PEAGRAVEL (3/8")

GROUND WATER DATA

DATE & TIME		DEPTH TO WATER & BOTT.	

DEPTH	STRATA	SAMPLE NO. SACK	JAR	DESCRIPTION OF MATERIAL
0	a			GRY. BRN. SI. CL. & ANG. RK. TO 3" ±, WET, PLS., EASY DRILL
				1" ANG. DRAIN RK., V. MOIST
10	b	OG*		SAME AS 0.0 FT. → 7.8 FT. W/ SOME BLK. PLASTIC GRID MATL. EASY DRILL
20	c			OLV. GRY. SI. CL. W/ ± 50% ANG. DRK. GRY. SD. ST. FRAGS., MOIST, SL. PLS., V. STIFF DRILL
30	d			BECOMING GRY., SATURATED, V. RUNNY
	e			OLV. GRY. SI. CL. & ANG. RK. TO 3", MOIST, SL. PLS., V. HARD DRILL
40	f			V. HARD ROCKY DRILL, MOSTLY GRY. SD. ST./SHALE FRAGS.
	g			UNABLE TO PENETRATE [illegible]
50				BOTT. @ 48.2, DRILL REFUSAL.
				* OG = 13' ? NEW [illegible] 5/19/97 [illegible]

REMARKS: P.B. FOR INSTALLING SLIDE INDICATOR CASING

NOTE: CASING LENGTH = 48.0 FT.

BEARING = N 55° W

SLOPE INDICATOR WILL BE CALLED "TENSAR - 1"

DL 320 (7/78)

DEPARTMENT OF TRANSPORTATION

POWER BORING LOG

DISTRICT 4

CO. SM RTE. 84 P.M. 10.05 AUTH. NO.

LIMITS SLIDE CORRECTION @ P.M. 9.82 & 10.05

OWNER STATE ELEV. DATUM

LINE. STATION FT. LEFT. RIGHT

DRILL RIG. 484

BORING DIA. 8" AUGER

PARTY CHIEF # NAKAJIMA

DRILLER SHAMAFOCK

JOB NO. 6393

BORING NO. P-2

PAGE 1 OF 1

DATE 1-23-85

CASING LENGTH 28'

TYPE PLASTIC S.I. DIA. 2.75"

BACKFILL 3/8" P. GRAVEL

GROUND WATER DATA

DATE & TIME		DEPTH TO WATER & BOTT.	

DEPTH	STRATA	SAMPLE NO. SACK	SAMPLE NO. JAR	DESCRIPTION OF MATERIAL
0	a			BRN. SI. CL. & ANG. RK. & RK. FRAGS TO 4", V. MOIST, PLS., EASY DRILL.
5				1" DRAIN ROCK, V. MOIST
10	b			BRN. & GRY. BRN. SI. CL. & ANG. RK. TO 2"±, MOIST, SL. PLS. EASY DRILL.
15	c			OLV. BRN. SI. CL. W/ ±30% ANG. RK. TO 1½", SL. MOIST ⇒ MOIST, N.P. ⇒ SL. PLS., STIFF DRILL.
20	d			SAME BUT LT. OLV. BRN., HARD DRILL
25	e			SAME BUT W/ INCR. IN AMT. OF RK., V. HARD DRILL.
30	f			OLV. GRY. SI. CL. & SML GRY. SD. ST. FRAGS, DRY, V. HARD, SLOW PENETRATION RATE.
				WATER ADDED TO HOLE.
				BOTT. @ 30' DRILL REFUSAL (30+ MIN PER FOOT).
				IS OB = 1.3 ... 1400 ... 5/19/85 ...

REMARKS: P.B. FOR INSTALLATION OF S.T. CASING

NOTE: CASING LENGTH = 28 FT.

BEARING = N 10° W

S.T. WILL BE CALLED "TENSUM-2"

APPENDIX D

CONSTRUCTION REPORT OF COMPLETION

Pages 57 - 61

STATE OF CALIFORNIA—BUSINESS AND TRANSPORTATION AGENCY GEORGE DEUKMEJIAN, Governor

DEPARTMENT OF TRANSPORTATION
BOX 7310
SAN FRANCISCO 94120
(415) 557-1840

MAR 2 3 1985

Contract No. 4-182174
Co-Rte-PM 4-SM-84-9.8/10.1
F.A.P. No. ER-1048(2) ER-1048(3)

W. E. Schaeffer,
Deputy Director for Project Development

Attn: H. R. Ginsberg, Chief
Office of Highway Construction

Dear Sir:

The following is submitted to you in accordance with current instructions:

REPORT OF COMPLETION

FOR

CONSTRUCTION ON STATE HIGHWAY

ABOUT 1 MILE NORTHEAST OF LA HONDA

COUNTY OF SAN MATEO

POST MILE 9.8/10.1

0.3 MILE

CONTRACTOR - O'GRADY PAVING, INC.

J. BROWNE
Deputy District Director - Construction

W. R. KLEMENS
Resident Engineer

A. DESCRIPTION

The work as let under Contract 4-182174 consisted of restoring slipouts by excavating and placing polymer mesh reinforced embankment, installing overside drains and permeable material, and placing rock slope protection.

B. CONSTRUCTION DETAILS

1. Unusual conditions and problems.

a. Significant changes from original plans and specifications.

When excavating ner toe of excavation at P.M. 9.85, ground water was encountered at a depth of 25 feet below existing roadway. Saturated clay was found 30 feet below roadway. The area with saturated clay was subexcavated 5 to 6 feet below grade and backfilled with Class 3 Permeable Material. In the area with groundwater seepage, the planned permeable blanked was increased from 1 foot to 2 feet.

At P.M. 9.85 the existing 12" CMP was removed and replaced with an 18" CMP with downdrain. At this same location, the existing drainage inlet was removed and replaced with an OSM D.I. with 2 side openings.

At P.M. 10.1 (Station 10+75), the existing 18" CMP and D.I. were plugged and abandoned. At Station 10+10, the existing 18" CMP was extended with a downdrain, and a Gl inlet installed for clean-out purposes.

At both slipout locations, the permeable blanked was extended across the bottom of excavation from the toe of excavation to toe of rock slope protection due to existing ground water.

The limits of Rock Slope Protection was extended on both embankments to provide for more rigidity and stability.

2. Production rates for major items of work.

Item	Average Daily Production
Roadway Excavation	77 CY
Structure Excavation	29 CY
Imported Borrow	76 Ton
Filter Fabric	111 Sy
Class 3 Permeable Matl.	26 CY
Place Polymer Mesh Reinf.	171 SY
Rock Slope Protection	52 Tons

C. CHRONOLOGICAL STATEMENT

Bids received August 2, 1983.

Contract awarded August 24, 1983.

Contract approved by Attorney General September 19, 1983.

Contract accepted by Director of Transportation October 10, 1984.

D. CONSTRUCTION MATERIALS

1. Sources of all major materials used.

Items	Source	Location
Imported Borrow	Langley Hill Quarry	Woodside
Asphalt Concrete	Raisch Products	San Jose
8" CSP	Pacific Corrugated Culvert	Sacramento
Filter Fabric	Cristina Whsle	San Jose
Cl. 3 Permeable Matl	Mission Valley Rock	Sunol
18" CSP DD	Pacific Corrugated Culvert	Sacramento
Polymer Mesh Reinf.	Tensar Corp.	Concord
Rock Slope Protection (1/4T)	Langley Quarry	Woodside

2. All materials were from commercial sources.

"Yes"

3. No mandatory sources were used.

E. CONTRACTOR'S CLAIMS

None

AM J. BROWNE
Deputy District Director
Construction

..ndum

To : W. E. SCHAEFFER
Deputy Director

Date: April 11, 1985

File : Road 04-SM-84-9.8/10.1

Project No. 04-182174
F.A.P. No. ER-1048(2) (3)

From : DEPARTMENT OF TRANSPORTATION - District 04

Subject: MATERIALS CERTIFICATE

This is to certify that:

The results of the tests on acceptance samples indicate that the materials incorporated in the construction work and the construction operations controlled by sampling and testing were in reasonably close conformity with the approved plans and specifications, and such results compare favorably with the results of independent assurance sampling and testing.

Exceptions to this certification are documented in the project records.

R. J. Jacobs

R. J. JACOBS

CHIEF, CONSTRUCTION BRANCH